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FIRST TOPICAL REPORT UPDATE

EVALUATION OF SPACE STATION SOLAR ARRAY TECHNOLOGY

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SPACE STATION SOLAR ARRAY PROGRAM

Prepared for

MANNED SPACECRAFT CENTER HOUSTON, TEXAS

By

SSD POWER SYSTEMS

LOCKHEED MISSILES & SPACE COMPANY, INC.
A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION
SPACE SYSTEMS DIVISION · SUNNYVALE, CALIFORNIA

Lockheed
MISSILES
& SPACE
COMPANY,
INC.

15 August 1972

To: Space Station Solar Array Technology Evaluation Update Report Recipients

In December 1970 the "Blue Book", or officially, "The First Topical Report" under contract NAS9-11039, was published which summarized all of the technical data available related to lightweight solar arrays, and orientation and power transfer assemblies. This report provides a review and evaluation of the work performed since that time and is being published in a manner that will allow insertion of the new information into the original "Blue Book" report. This report contains an annotated bibliography, as did the first report, and it is suggested that both bibliographies be combined and inserted in this smaller cover to provide room for insertion of the new technical data into the original three-ring notebook. The updated information has been printed on colored pages to enable the "Blue Book" user to easily find the newest information.

I would like to express my appreciation to all of the people throughout the industry who provided photographs and technical data for this report.

L. G. Chidester

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LGC:jd

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Section 1
INTRODUCTION

A total of three topical reports were published documenting the major activities on the Space Station Solar Array Program under contract NAS9-11039. The first of those published in December of 1970, was a complete review and evaluation of the available technology which might be applied to the design of a 10,000 ft^2 Space Station Solar Array. That topical report, LMSC A981486, which will be referred to as the "Blue Book" throughout this report, was published in a loose-leaf notebook so that it could be updated periodically to provide solar array designers with a summary and evaluation of the most recent work in this field. The purpose of this report is to summarize the work performed since 1969-70 concerning lightweight solar array assemblies and also to include any work that was missed in the original material search.

In addition to the review and evaluation of available solar array technology, the original document contained two other significant sections; (1) a list of studies recommended to be performed to fill technology gaps or provide a beneficial weight or cost advantage and (2) an annotated bibliography which abstracted and categorized every technical report reviewed during that task. With respect to those items, this report provides (1) a summary of the work accomplished and the work planned on the Recommended Studies and (2) a supplement to the bibliography abstracting all documents reviewed and abstracted for this updated report. That information is presented in the following sections of this report:

2.0 Summary - Brief description of the material reviewed and reported on and a complete summary of work performed on the Recommended Studies.

3.0 Study Methods and Data Source Description - Summary of data sources and methods of obtaining reports.

4.0 Technology Evaluation - Presentation and evaluation of available technology. Note: Section 4.2 (ODAPT) has been deleted from this update because of termination of the drive system portion of the study efforts.

5.0 Bibliography - Listing, in alphabetical order, of documents used for reference in compiling this report. This listing updates the Bibliography of the First Topical Report and should be used in conjunction with that original list of documents.

Section 2.0
SUMMARY

A major solar array technology milestone occurred during 1971 with the successful flight testing of a flexible roll-out solar array. Details of that design were reported extensively in the Blue Book (L. 4-47) and available flight data results are included here.

Technology advancements and what may turn out to be major breakthroughs were accomplished with the advent of 18% gallium arsenide solar cells, wraparound contact solar cells, lithium doped solar cells, extendible-retractable structures, array packaging techniques, adhesiveless solar cell array assemblies, large area array testing methods, slipring-brush material development, lubricant evaluation, and solar cell assembly fabrication techniques.

All of the above items are discussed in this report as well as flexible array concepts now being developed by European Satellite teams.

Most of the technical data is presented in Section 4.0 which discusses and evaluates the available technology. Section 4.2 (the orientation and power transfer section) has been omitted since Ball Brothers Research Corporation provided the information for the Blue Book and their subcontract was completed prior to preparation of this update. However, the extensive work performed by BBRC on this program represents a major portion of the applicable technology work accomplished since 1969 in the drive system and power transfer areas and this work is reported in detail in the Second and Third Topical Reports, LMSC-A995719 and LMSC-D153526, respectively.

A major goal of this program was to identify solar array technology areas where additional development should occur and to recommend specific studies which could be conducted to fill in the technology gaps. A total of 34 studies were recommended in three categories (Section 5.0 of the Blue Book) as follows:

Category I	-	Projects Planned to be Conducted on the Space Station Solar Array Contract
Category II	-	Additional Projects Recommended to Ensure Technology Readiness
Category III	-	Projects Recommended to Provide Significant Down-Stream Improvement

One method of measuring the effectiveness of this program and to evaluate the state of "Technology Readiness" at the time this Blue Book "Update" is published is to summarize those recommended projects and the work that has been completed or is currently planned on those studies. The following three (3) charts were assembled to provide that information. Chart 2-1 discusses the studies proposed under Category I, Chart 2-2 discussed those in Category II and Chart 2-3 discusses those recommended in Category III. Of the 34 studies recommended only 4 have had "no activity" performed on them since the Blue Book was published. Three of those were in the "Critical" Category with respect to the immediate development of a Space Station Solar Array and pertained particularly to a flight readiness development program. For lightweight solar array design and use in general it seems that some activity is either planned or underway in every significant area.

Chart 2-1

RECOMMENDED TECHNOLOGY PROGRAMS

Category I - Projects Planned to be Conducted on the Space Station Solar Array Program

RECOMMENDED STUDIES	SUMMARY OF RECOMMENDATIONS	CURRENT OR COMPLETED ACTIVITY	PLANNED ACTIVITY
1. SPACE STATION SHADING STUDIES	Vehicle on array shade factors are used as basis for radiator location and electrical design. Shading patterns, as a function of inclination angle and vehicle position in orbit, along with shade sweep direction should be determined. Photographic shading and computer analyses should be made for selected configurations to determine power output losses.	Preliminary studies at LMSC (L. 4-48 Appendix B. 4). Shadowing study by JPL Venus Mercury Fly-By-Solar Panel (N. 4-24). TRW Array Shading Studies for ATM, OWS.	Additional shading study will be performed when Space Station configuration is fully defined. Shading model and computer program available for this purpose.
2. BASIC SUBSTRATE MATERIALS EVALUATION	Mechanical properties determined over required temperature ranges. Changes in properties due to UV, vacuum, and prolonged temperature cycling. Specimens must include laminates and module joints. Determines parametric life data.	Creep, Tensile, and Tear Tests at LMSC (L. 4-37 and L. 4-57). Creep properties compilation by Allied Chemical (A. 7-1). Creep behavior of polymers (I. 1-2).	NASA MSFC contract NAS8-28432 with LMSC to study basic materials involved, and optimize flexible substrate design.
3. SUBSTRATE PACKAGING EVALUATION	Large area flexible array packaging designs, including rollup, flat foldouts, and others requiring either integral or separate padding techniques require full scale feasibility and performance demonstration and evaluation. Mechanical complexity added to the automatic repackaging during retraction requirement set the pace here.	Lockheed flatfold studies and test (L. 4-47, L. 4-48, L. 4-57). General Electric final rollup tests (G. 2-9 and G. 2-21).	Possible shuttle-launched experiment under consideration by MSFC.
4. DEPLOYABLE STRUCTURE TEST AND EVALUATION	The central mechanical component of any packaged flexible solar array system is the extendible boom which deploys and retracts the panels. All types of booms should be fabricated and tested (small and full scale) to determine characteristics for future designs. Data should include unloaded alignment, stiffness, buckling (lateral and column loads) and packaging values.	Lockheed tests on Astromast (L. 4-57). General Electric tests on SPAR (G. 2-9 and G. 2-21).	NASA MSFC/MSC CVT program will perform additional evaluation testing of Space Station Solar Array hardware.
5. DEPLOYMENT DRIVE AND TENSIONING MECHANISM EVALUATION	These devices control boom deployment, array segment retraction, and uniformity of substrate tensioning under variable orbital load conditions (0 to 1 "g"). Substrate length variations due to thermal growth and creep must be considered. Scale-up data and definition of cost in weight and complexity for candidate systems should be obtained.	Design support and major hardware tests by Lockheed (L. 4-48, L. 4-47).	(Same as above)
6. FULL-SCALE ARRAY ASSEMBLY TESTING	To evaluate design concepts and analytical procedures used in design and to assess problems in fabrication, assembly, and test, full scale tests of the major array components should be conducted. These tests would provide simultaneous evaluation of ground handling methods and mechanical/electrical acceptance test techniques.	Lockheed Array Quadrant tests (L. 4-57). General Electric rollup tests (G. 2-9 and G. 2-21).	(Same as above)
7. LUBRICATION TESTS	No one lubricant can perform properly for all required space applications. Tests must be conducted to select the best lubricant for each requirement. Operating modes which cause cold welding, increase viscous drag, increase start and running torques, and cause surface degradation of bearing elements must be determined and solved.	Design support tests by BBRC (L. 4-57)	May be included in CVT life testing.
8. DRIVE MOTOR EVALUATION	Ten-year vacuum operation, periodic maintenance, and component replacement requirements, coupled with the large stall torques of the tracking system demands thorough evaluation and performance testing of current commercially available motors before final design selection.	Design support tests by BBRC	(Same as above)

Chart 2-1 (Cont'd)

RECOMMENDED STUDIES	SUMMARY OF RECOMMENDATIONS	CURRENT OR COMPLETED ACTIVITY	PLANNED ACTIVITY
9. FULL SCALE DRIVE SYSTEM EVALUATION	No automatic 2-axis orientation system of this size with manual override provisions has ever been tested. No such system has sustained loads in a high artificial "g" field. A test model should be tested under simulated docking and spin mode stresses and launch loads. Tracking and gear dynamics should be studied.	Interaction Study by Fairchild-Hiller (F.1-13, F.1-14, F.1-15). Major hardware fab and test by BBRC (L.4-48, L.4-47). NASA Goddard work (N.2-19).	NASA MSFC/MSC CVT program will perform additional evaluation testing on Space Station Solar Array hardware.
10. MAINTAINABILITY: BEARINGS, BRUSHES, MOTORS	Drive systems to date have light loads and are of small size. The long duration (10 year) space station application makes an effective maintenance/replenishment philosophy mandatory. Major hardware endurance testing coupled with degradation failure mode analyses and design complexity assessments should produce required results.	No activity identified except the information obtained and reported in the Space Station Solar Array Program Topical Reports, NAS9-11039.	No activity planned. Should be done in conjunction with overall Space Station studies.
11. TRACKING SYSTEM DUTY CYCLE ANALYSIS	Determination of the total travel and rate requirements of the two-axis drive system for various possible Space Station flight modes (computer analysis). Evaluation of the impact of these on drive and power transfer hardware design and design complexity.	Preliminary analysis and design by BBRC (L.4-48). Work by Hughes Aircraft for Air Force (H.6-29). Lockheed/MSC Gimbal and Drive Study (NAS9-11874)	No activity planned.
12. SLIP RING MATERIAL EVALUATION	This test series will determine the effect of static and slow speed sliding performance of power-type brush/slip ring combinations in vacuum. Tests should be conducted over a range of brush pressure, current density, lubricant types, and speeds from 0 to 6 degrees per minute to determine friction and wear rate.	Hardware design and tests by BBRC (L.4-48, L.4-57).	May be included in CVT life testing.
13. FLEXIBLE CABLE EVALUATION	Test information relative to flex cables alone or in combination with various power transfer devices is critical to final design. Maximum life limiting factors, stiffness of cabling carrying 100,000 volt-amperes with minimizing torque, power consumption, and cooling requirements is desired. Vacuum cycling ±180 degree flexure tests on cable configurations is required.	Weight and volume tradeoffs conducted on NAS9-11039 by BBRC (L.4-48).	No activity planned.
14. FULL SCALE POWER TRANSFER TESTS	Key problems associated with space station solar array power transfer involve scale-up of present capability and physical unit size, coupled with 10 year life. A power transfer model with full scale current density and thermal configuration should be thermal vacuum tested to determine friction drag, temperature rise, power dissipation, wear, and electrical noise.	Tests on Space Station Major Hardware components by BBRC (L.4-57).	No activity planned.

Chart 2-2

RECOMMENDED TECHNOLOGY PROGRAMS

Category II - Additional Projects Recommended to Ensure Technology Readiness

RECOMMENDED STUDIES	SUMMARY OF RECOMMENDATIONS	CURRENT OR COMPLETED ACTIVITY	PLANNED ACTIVITY
1. TEMPERATURE CYCLING PROGRAM	Survival of the Space Station Solar Array over 58,000 temperature cycles in low earth orbit over ten year life requires comparative data (non-existent) on candidate cell/substrate assemblies to determine designs which will withstand this environment. To demonstrate this capability, a high test sample capacity facility with "in situ" output measurement capability should be built. Test results should reveal basic failure mechanisms.	Temperature Cycling Plan by Lockheed (L.4-58), published in August 1972. Other activities as described in Table 4.1.16 of this report.	Temperature cycling program set up to standardize method of temperature cycle testing and to evaluate flexible array modules–follow-on to NAS9-11039. In-house cycling of advanced modules planned at MSFC.
2. FLEXIBLE INTERCONNECT DEVELOPMENT	Tests in this program should include high and low temperature fatigue and tensile tests of candidate materials (copper, kovar, molybdenum, aluminum, aluminum-40% copper and silver), and geometry combinations applied both to adhesive-bonded and integral-pointed circuit flexible substrate assemblies. Promising approaches using appropriate joining techniques and solar cell assemblies should be fabricated for inclusion in temp. cycling test program, (1) above.	Integral substrate-interconnect laminates by Lockheed (L.4-48). Development work at TRW under Air Force contract (T.3-36). Also, Ion Physics (I.3-14).	Interconnect materials study and evaluation by testing planned for NAS8-28432 contract to be performed by LMSC with MSFC.
3. SOLDERLESS JOINING TECHNIQUES	No standardized test programs exist to develop and compare solderless interconnection methods. Solar cell assembly techniques including brazing, welding, ultrasonic bonding, and thermocompression should be investigated and comparatively evaluated. Promising methods for flexible cell assemblies should be incorporated in temp. cycling test program. Cost reduction and ease of repair should be emphasized.	Being developed by Lockheed under MSFC Huntsville contract (final report in April 1973) NAS8-28432. New contract, NASA-LeRC, with TRW. Spectrolab contract with COMSAT Labs.	Solderless joining technique development will be included in NAS8-28432, described above. Testing to be done at MSFC.
4. UV AND IRRADIATION TEST – FLEXIBLE SUBSTRATES	Long term effects of combined vacuum, ultra violet, and penetrating radiation on the structural and thermal properties of the polymeric substrate materials, used as major structural components, should be determined by a test program. Post-radiation tensile and creep testing (-250°F to +200°F range) should be included on candidate substrate materials such as Kapton, FEP Fiberglass, and laminates of these materials.	Tensile, tear, and creep tests by Lockheed (L.4-57) – temperature only – no environments.	Classified projects working on effects of irradiation on flexible substrate assemblies.
5. FLEXIBLE ARRAY THERMAL PROPERTIES DETERMINATION	Test data on thermal and optical properties (emissivity, absorptivity, transmissivity, reflectivity, specific heat, coefficient of expansion, and thermal conductivity) of the flexible substrate materials and laminates, solar cells and solders, as a function of temperature down to -300°F, are required for both design and the thermal cycling program. This program should be combined with the Radiation Program.	Being compiled by Lockheed under MSFC Huntsville contract (Final Report in April 1973) contract NAS8-28432. (Reference Category I – Items 2 & 3)	Work to be performed on NAS8-28432 through 1972.
6. STORAGE/LIFE TESTING OF ERECTION/ RETRACTION COMPONENTS	Flexible solar cell arrays require preloads for ascent protection. These preloads are provided in drum rollup systems by substrate tensioning, and in flat-fold systems by compression between structural covers. Both systems employ padding material for cell protection. Permanent set (edge curl for drum configurations and creases for flat-fold) and environmental effects under long storage could result and should be determined. Structural components such as springs, cables, and bearings should be included as to long exposure to space environment effects.	No activity.	Will be included in NASA MSFC CVT program to evaluate Space Station hardware.

Chart 2-2 (Cont'd)

RECOMMENDED STUDIES	SUMMARY OF RECOMMENDATIONS	CURRENT OR COMPLETED ACTIVITY	PLANNED ACTIVITY
7. ARRAY-STATION INTERACTION STUDY	Determination of dynamic compatibility based on a model simulating Space Station structure, solar array structure, and Space Station guidance and control system. Present program does not include artificial gravity model. Development of dynamic model (continuous improvement) using inputs of test program results (boom stiffness, mass properties, substrate tension, and actual tracking drive properties is required.	Computer programs being developed and used by Fairchild-Hiller (F.1-13, F.1-14, F.1-15).	Additional work to be performed by NASA-MSC when results of additional structural characterization testing are available.
8. ALTERNATE LARGE BEARING SYSTEM TEST	Bearing or roller system could transmit total dynamics loads between two large cylinders (solar array boom and space station power boom). Little known in the area of large ball bearings and small rollers. A full scale bearing and drive structure must be fabricated for testing and evaluation of rolling friction starting torque, wear for either roller or ball systems.	No activity identified.	No activity planned.
9. LIFE TESTING – DRIVE SYSTEM	Continuation and extension of Category I – Program 9 testing. Replaces the idea of evaluating long term effects by accelerated tests which could give misleading results. Hardware from Category I – Item 9 with slight modification can be used here.	BBRC test program (L.4-57).	May be a part of NASA MSFC-CVT program.
10. ENVIRONMENTAL LIFE TESTS – POWER TRANSFER ASSEMBLY	Continuation and extension of Category I – Program 14 testing. Will increase the accuracy in operational performance prediction.	No activity identified.	No activity planned for full scale testing.

Chart 2-3

RECOMMENDED TECHNOLOGY PROGRAMS

Category III - Projects Recommended to Provide Significant Downstream Improvement

RECOMMENDED STUDIES	SUMMARY OF RECOMMENDATIONS	CURRENT OR COMPLETED ACTIVITY	PLANNED ACTIVITY
1. TEFLON COVER EVALUATION	Inadequate process and production technique optimization and environmental testing for this newcomer as coverglass material. Applicable to any size power system with great weight and cost savings potential. Tests measuring degradation of teflon covers by particle and UV radiation and determination of thickness to application/environment are required.	• Lockheed investigation for NASA-LeRC (L.4-34 and L.4-42). • NASA LeRC contract with TRW initiated February 1972 to fabricate and test heat-bonded teflon covers for solar cells.	Continuation of TRW/LeRC work. LMSC ID work on spray-on teflon solar cell covers.
2. INTEGRAL SOLAR CELL COVERS	Integral covers can be 1-2 mils, as compared to 6 mil minimum for conventional coverglasses. Significant weight reduction and elimination of the adhesive would result. Development of processes and material for use with standard cell manufacturing techniques and of production capability is required. Heavy process development expenditures should not be made until this approach is compared with Program 1 (above) results.	• Development work by Heliotek (H.3-21 and H.3-24) and Texas Instruments (T.2-1). • Solar cell coverglass development by Ion Physics (I.3-16, I.3-17). • In-house development by NASA Goddard and NASA LeRC (N.2-28, N.6-27, N.6-40 and N.6-43).	GE funded by JPL for spray plasma deposition of ultra pure fused silica without stress problem.
3. IMPROVEMENT OF EOL SOLAR CELL EFFICIENCY	Investigations state theoretical attainable efficiencies up to 22%. These higher efficiencies can be achieved only by a better understanding of the physical phenomena governing solar cell performance. Electrical degradation in the cell due to UV and particle radiation, as well as repeated temperature cycles, should also be reduced. Testing to evaluate improved cells should be carried out at one central facility to better control conclusions.	• Lithium doping (H.3-20, H.3-25, C.3-12, C.3-16, A.1-8, R.1-25, R.1-26, R.1-31, N.4-22, J.1-1). • Efficiency improvement (P.1-4, P.2-7, N.7-12, N.7-13, N.4-2, N.4-16, N.4-34, C.9-1).	• Centralab and Heliotek will continue development work with NASA LeRC to improve cell efficiency to 20%. • IBM will continue development efforts in Gallium Arsenide cells to verify performance of 18%.
4. WRAPAROUND CONTACT SOLAR CELLS	Development of backside contact cells would result in cost reductions of up to $200/ft^2 by reducing the complexity of panel assembly. Present series connection to the top electrode calls for generous stress relief series tabs and increased cell spacing complicating assembly. Whereas backside contact cell will allow fully automated assembly, reduce series spacing, and padding thickness and weight.	• Heliotek development work (H.3-26 and H.3-19. • Centralab development work (C.3-13 and C.3-17). Under above contracts wraparound contact cells were developed for both LMSC and Lewis Research Center.	Evaluation of wraparound contact cell application will be performed on NASA MSFC contract NAS8-28432 and on NASA MSC contract NAS9-11039, both with LMSC continuation of LeRC work.
5. STANDARDIZATION OF SOLAR CELL SPECIFICATIONS	Some cell procurement specifications are directed at cell appearance (cosmetic) rather than proven performance criteria. There is a need for specific performance data as function of contact or ohmic strip width, chips and nicks, contact pinholes, and color variations. A joint NASA/industry study team should review the case and prepare a standard cell procurement specification.	• Effort by JPL cell calibration on high altitude bellows (N.4-50).	An industry and government agency meeting was held by JPL on July 17 & 18 to discuss industry and government viewpoints on standardization. Results not yet published at time of writing. A serious effort is underway.
6. COST EFFECTIVE CELL AND COVER PROCUREMENT	Cell production spans should be preprogrammed to increase production personnel competence (eliminate reassignment and layoffs) and to improve vendor facility and personnel use. This would result in reducing cell costs and in higher quality production. Solar cell production should be administered by a central NASA-Air Force procurement office to a common procurement specification (5 above).	(Same as above)	(Same as above) Terrestrial low cost studies directed out of NASA Lewis (part of A.D. Little team).

Chart 2-3 (Cont'd)

RECOMMENDED STUDIES	SUMMARY OF RECOMMENDATIONS	CURRENT OR COMPLETED ACTIVITY	PLANNED ACTIVITY
7. INTEGRATED POWER MODULES WITH ON-ARRAY ELECTRONICS	Multiple electronic modules for voltage regulation and limiting voltage and for fault isolation, mounted directly on the solar array modules, should be thoroughly investigated. Could replace present by-pass diodes and zener diode voltage limiters. Effort should concentrate on comparative testing of circuit elements and of alternate concepts. Electrical testing should be conducted on the panel module level and be directed at heat rejection.	Boeing studies of Hi-voltage solar arrays (B. 3-28 and B. 3-29). Hi-voltage array work by Hughes (H. 6-32 and H. 6-33).	No activity planned for Space Station Systems.
8. OPTICAL FILTER EVALUATION	Determine the exact degree of "blue" filter protection to cell and adhesives and find a pure "red" filter that does not degrade in space environment and which would reflect all light energy about 1.2 microns in wavelength. A study of all AR coating should be conducted to find one with low reflectance, high transmission, with low or no degradation. Blue filter elimination would save $0.32 per coverglass. Good red filter would produce 8% increase in power output.	JPL Boeing work on solar cell filters (B. 3-31 and B. 3-32) for Mercury/Venus mission for control of solar array temperatures.	OCLI Studies on reflective filters aimed at rejection of 30% additional solar energy, which could lower temperature by 50°F.
9. COMPOSITE STRUCTURE MATERIAL AND JOINING TECHNIQUES	Generation of basic properties of advanced composites, such as graphite/organic materials, is required for flexible solar array deployment structure. Creep fatigue effects from temp. cycling and bonding methods should be investigated. Fabrication of shapes, and testing of these structurally and thermally, should be considered. There is a high potential payoff in weight and stiffness.	Graphite/epoxy truss members and flexible lenticular sections fabricated and tested at Lockheed under in-house funding.	Full scale truss sections to be built and demonstrated at Lockheed.
10. TEST/EVALUATION OF ALTERNATE POWER TRANSFER DEVICE	Slip rings or flex harness are the only flight demonstrated methods. Power clutches and rotary transformers are relatively new. Power clutch needs development of face plate materials and lubricants. Rotary transformers require scale-up and experimental work for high power applications. Development models of each should be constructed and tested similar to slip ring tests.	Contract effort identified for INTELSAT Programs.	Comsat investigating rotating transformer at Philco Ford and rolling bi-stem type elements at Spar Aerospace. Liquid metal power transfer considered for Canadian Tech.

Section 3.0
STUDY METHODS AND DATA SOURCE DISCUSSION

To extend the review of the technology potentially applicable to space station solar arrays, several data acquisition/extraction methods were used. The services of the Lockheed Technical Information Center (TIC) staff were employed in performing data acquisition. The TIC surveillance of literature initiated at the beginning of the program was continued at a low level throughout the extent of the contract. Personal contact with the major government and industry centers was also continued to supplement and clarify the published data and to assess technology gaps in addition to correspondence via mail or telecon with those engineers who are active in the applicable associated disciplines.

A major source of new data resulted from the work performed under this contract, however, most of it is reported extensively in the Design and Analysis Topical Report (LMSC-A995719) and the test topical report (LMSC-D153526) and is not reported in detail here.

The literature search and evaluation methods employed were identical to those discussed in the original First Topical Report (L.4-47). The major items of review in this activity have been technical and scientific abstracts distributed periodically. Summary lists of technical journals, technical paper title/author listings, and regularly received reports were submitted to program engineering so that only pertinent reports were ordered. In all, some 350 reports additional to those reviewed in the Blue Book (L.4-47 LMSC A981486, December 1970) were evaluated for this supplement.

The documents used in this Special Project Task were reviewed only for new and/or improved applicable designs, techniques, test methods, etc. over and above those published in the original First Topical Report.

It is hoped that the data accumulated and categorized in this topical report will be of value in future programs where large area flexible arrays are applicable. In addition to the employment of specific data from the references in the various topical sections of this report, each reference was listed in the bibliography along with an indication of the subject matter covered and its possible applicability to the Space Station Solar Array design problems.

Section 4
EVALUATION OF AVAILABLE TECHNOLOGY

The data and information presented in the First Topical Report specifically covered the time span 1965 to 1969 inclusive. The data presented in this supplement covers approximately the years 1969 to 1972, with the exception of a few older documents overlooked in the original literature review. Furthermore, this report retains the original format, section, and paragraph callouts so that the pages appearing herein can easily be inserted at the end of each designated section in the initial document. No attempt was made to repeat the charts and text from the original topical with additions, deletions or substitutions. In the interest of time and cost savings, narratives were held to a minimum. In each subject section brief discussions and evaluations of the information available are made.

4.1 SOLAR ARRAY AND STRUCTURE

Structural, mechanical, electrical, and material data pertinent to the design, fabrication, and test of the flexible solar array substrate and deployable structure components of a Space Station Solar Array system are included in this section. As in the "Blue Book" the technology is discussed in three sections:

- Flexible Array Systems (4.1.1) - Information obtained from integrated flexible array systems continuing or initiating development in the last two years.

- Solar Array Structures (4.1.2) - New or improved basic approaches and technology, if any, applicable to deployment retraction and packaging.

- Solar Array Substrate Assemblies (4.1.3) - Technology applicable to design of the flexible power-producing module assembly.

As in the original First Topical Report, due to the large structural scale-up associated with the Space Station Solar Array, only conceptual fallout in the overall structural design area resulted from the current literature review.

4.1.1 Existing Flexible Array Systems

Two domestic systems, already reported on in the initial Topical Report, have continued and completed their contracts through this update period: (a) the General Electric JPL contract 952314 "Rollup Subsolar Array" completed its test program and final report on February 1, 1971; (b) the Hughes Aircraft AFAPL contract F33615-68-C-1676 "Flexible Rolled-Up Solar Array" was successfully launched on the U.S. Air Force SESP 71-2 Thorad Agena flight on 17 October 1971 and has operated successfully in excess of six months at the time of this writing. The flight has demonstrated the feasibility of launching and deploying flexible substrate solar arrays.

The most recent U.S. flexible array design information available was that generated under this contract, NAS9-11039, and therefore some of the information from the design and development of the 10,000 ft^2 Space Station Solar Array will be summarized

as part of this Technology Evaluation Update. Most of the data has been published in the "Blue" or "Red" Books, however, and will not be repeated here.

Advanced (flexible roll-up and fold-up) solar panel concepts are being explored and developed in West Germany by both AEG-Telefunken and MBB Messerschmitt-Boelkow-Blohm. The former company is concentrating on a deployable rollup or window shade type of solar array (somewhat akin in design to the Hughes SESP type) to be used on a direct broadcast communications satellite. The latter company is engaging its engineers in refining an unusual technique for deploying large solar arrays from a stowed condition.

Design and performance characteristics available on these five flexible solar array systems will be presented in Section 4.1.1.1. Test results considered significant will be discussed in Section 4.1.1.2. The dynamic analysis performed under contract with Fairchild-Hiller studying interaction between a space station and its solar array (NASA Langley contract NAS1-10155) will be reported here with interim results of the analysis and digital simulation discussed briefly in Section 4.1.1.3.

4.1.1.1 Existing Flexible Arrays

Although there was probably more work accomplished on flexible array development during the last year than during any single previous year, very few reports were published describing that work. As mentioned previously, the Hughes flexible array (FRUSA) was successfully flight tested, General Electric completed the environmental testing and analysis on their flexible array, and the full scale 2500 ft^2 Space Station Array Quadrant was tested at Lockheed. Further testing is scheduled on the Lockheed array during the Concept Verification Testing (CVT) Program at Marshall Space Flight Center in Huntsville and at the Manned Spacecraft Center in Houston. Development work is also progressing at a rapid rate on the European flexible arrays and all available technical data is presented here.

Basic characteristics of the four major flexible arrays are presented in Table 4.1.1. The discussion of design comparison between the concepts was included in the "Blue Book" (L.4-47) and is not repeated here. There is some later data regarding performance (watts/pound) such as: LMSC - 18 watts/pound; G.E. - 30 watts per pound; Hughes - 22 watts per pound; and ESRO - 22 watts per pound. The numbers are based on including all necessary mounting, extension and retraction hardware with the basic array substrate assembly. It is difficult to make objective comparisons between the concepts; however, there are some obvious reasons for the difference in weight such as G.E. using 3 mil cover slides, Hughes using 6 mil cover slides and LMSC using 12 mil cover slides. Also the total array size can have a major impact on weight/ft^2, with the larger area allowing reduced mounting and extension weight per square foot of array. Design requirements for each of the arrays were quite different too; for example, the Space Station array structure had to withstand up to 1.0 "g" loading (art "g" experiment) while the other arrays were designed for normal orbital loads of 0.1 "g". Suffice it to say that any of the above systems, given sufficient development time and funding could satisfy the basic Modular Space Station packaging volume, weight, and size constraints. A major result of the Space Station Solar Array Program was proving the feasibility of easily retracting huge flat-fold arrays which appear to have the optimum stowed volume and shape configuration for flexible arrays.

TABLE 4.1.1

GENERAL DESCRIPTION - CURRENT FLEXIBLE SOLAR ARRAY SYSTEMS

CONTRACT	TITLE	COMPANY OR AGENCY	DIMENSIONS SIZE	POWER/WT WATT/LB	PROGRAM STATUS	APPLICATION (MISSION)	RETRACT-ABLE	STOWAGE METHOD	BIBLIOGRAPHY NO.
1) NAS9-11039 MSC-Houston	Large Space Station Solar Array	LMSC	10,000 ft^2 (2500 ft^2 Quadrant - 90' by 36' fabricated)	18 watts/lb	Fabricated/quadrant for feasibility Ground Test Final Report - August 1972	Shuttle Modular Space Station	Yes	Flat Foldout	L.4-47 L.4-48 L.4-56
2) Cont. 952314 NASA-JPL	Rollup Subsolar Array	GE (Valley Forge Space Center)	250 ft^2	30 watts/ lb	Ground environmental and performance tests completed October 1970 Final Report - February 1971	Interplanetary Probes	Yes	Drum Roller	G.2-9 G.2-21
3) F33615-68-C-1676 Air Force - APL	Flexible Rolled-Up Solar Array	Hughes Aircraft	166 ft^2	22 watts/ lb	Flight tested on Agena October 1971 Final Report - July 1972	Experimental Air Force Vehicle	Yes	Drum Roller	H.6-7 thru -13 H.6-37 thru -4[illegible]
4) ESRO	--	AEG - Telefunken	108 ft^2	22 watts/ lb	Design study and demonstration model only. No reports available	Planned for Direct Broadcast TV Satellite and CTS Satellite	Yes	Drum Roller	Aviation Week 24 Apr 1972 Communication Forestieri-Lott

4.1.1.2 Testing Performed on Flexible Array Systems

Significant major tests in the field of flexible solar arrays, accomplished during 1970-71, are summarized in Table 4.1.2. The first two series of tests shown (the GE and LMSC arrays) were ground feasibility tests. The third test reported here concerns the space flight of Hughes FRUSA (Flexible Rolled-Up Solar Array). A brief description of each of these system tests follows.

(A) General Electric Rollup Subsolar Array Tests (see G.2-29 and G.2-21 for details).

Two basic series of tests were conducted on the array system shown stowed and fully deployed in Figures 4.1.1 and 4.1.2: a series of environmental tests – pyrotechnic shock, thermal vacuum, acoustic noise, and both sinusoidal and random vibration; and a series of tests consisting of vertical deployment and retraction, electric performance, deployed thermal bending, deployed dynamics (both out of and in plane) and finally drum wrap tension (stability in vibration). The tests with summary results are shown in Tables 4.1-3 and 4.1-4.

The test program in general achieved the major objective of providing a technology data base for this type of large area, lightweight deployable solar array. Many test techniques applicable to other design configurations were conceived, developed and demonstrated.

The environmental tests demonstrated that the design was capable of withstanding a range of environments that should include the launch vehicles applicable to this equipment. Conventional test techniques are sufficient. New data on the dynamic response of rolled up solar array blankets were obtained. The amplification factors were low with respect to all forms of excitation: pyrotechnic shock, acoustic, and mechanical vibration.

The performance tests involved unusual test techniques that were necessary because of the large size of the system and its lightweight structure. State-of-the-art advances were made in low frequency dynamics testing and in measuring the displacements of structural members with electro-optical instruments.

Aerodynamic forces, significant because of the large area of these systems, can be eliminated by testing in a vacuum. Facility capability is a constraint on the size of this equipment category if full scale tests cannot be avoided.

TABLE 4.1.2

FLEXIBLE SOLAR ARRAY - MAJOR HARDWARE TESTS

COMPANY	SPECIMEN	DESCRIPTION OF TESTS	RESULTS
LMSC Contract NAS9-11039 MSC-Houston	1 Quadrant of 10,000 ft^2 Space Station Solar Array 4 strip-mylar Mockup 1 strip-3 modules solar cells	• Astromast static load tests for zero and artificial g space station requirements • Array Quadrant Series of deployment and retractions	• No mechanical failures during demonstrations • Proof of packaging techniques
GE Contract JPL-952314	2 Blanket/cylindrical drums for each Total array area 250 ft^2 Each blanket 33.5' x 4' dimensions	• BiStem Thermal Bending tests • Systems Level Tests: Deployed dynamics pyrotechnic shock, thermal-vacuum, stowed dynamics • Throughout tests array blanket and mechanical inspections for damage or breakage	• Dominant test problem accommodating gravity forces so as to eliminate interference with tests • Achieved major objectives conceived new test techniques
Hughes Contract F3365-68-C-1676	2 Blanket/common cylindrical drum Total array area 165 ft^2 Each blanket dimension 14.8' x 5.5'	• Flown on Space Test Program (STP) 71-2 vehicle - completed 8 full months of operational service to date • Successfully performed 10 complete rollups and rollouts and 2 partial extensions/retractions (1/3 and 1/6)	• Generated the required 1465 watts • Telemetry data system failure limited flight performance information

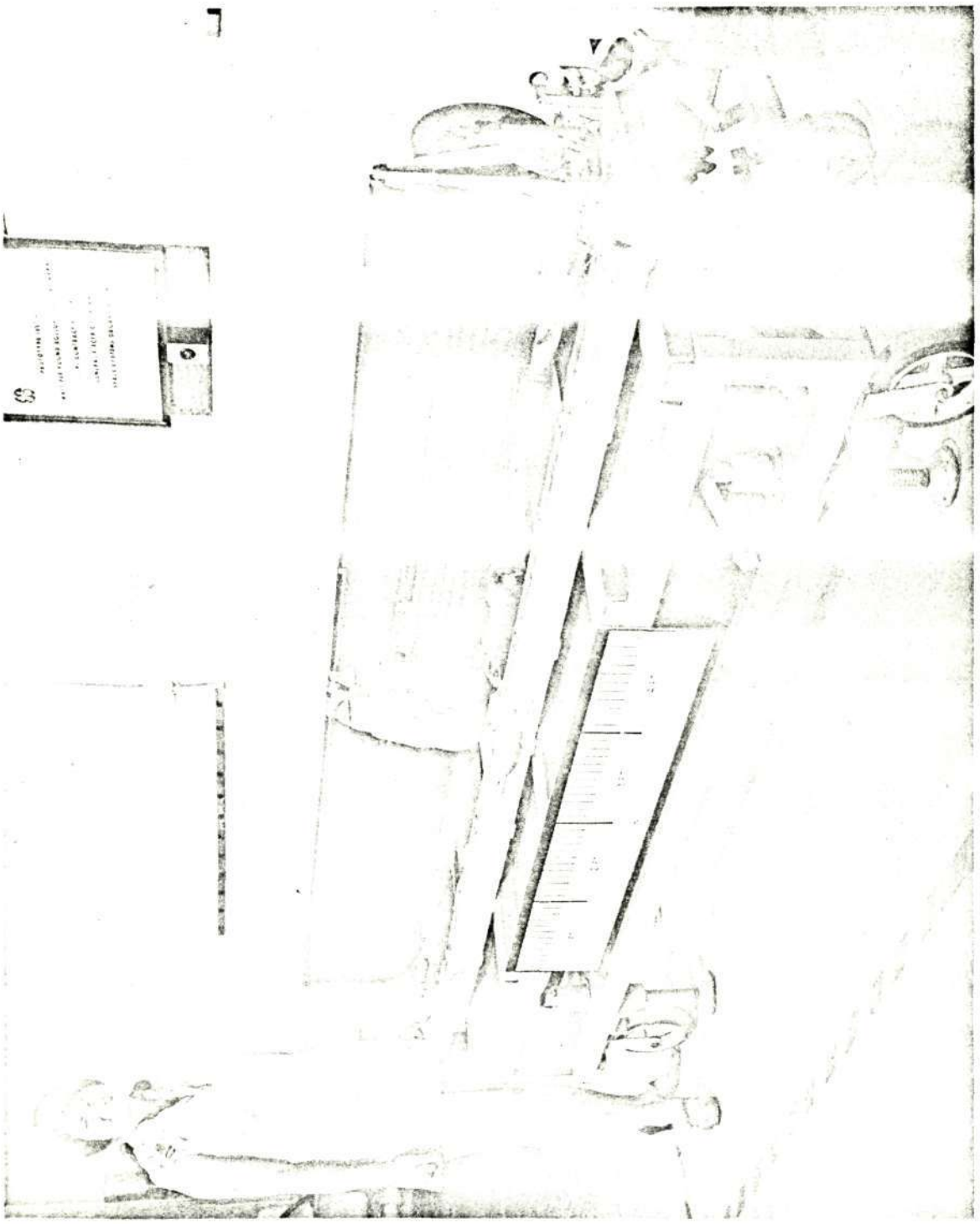


Figure 4.1.1 G.E. Rollup Array - Stowed

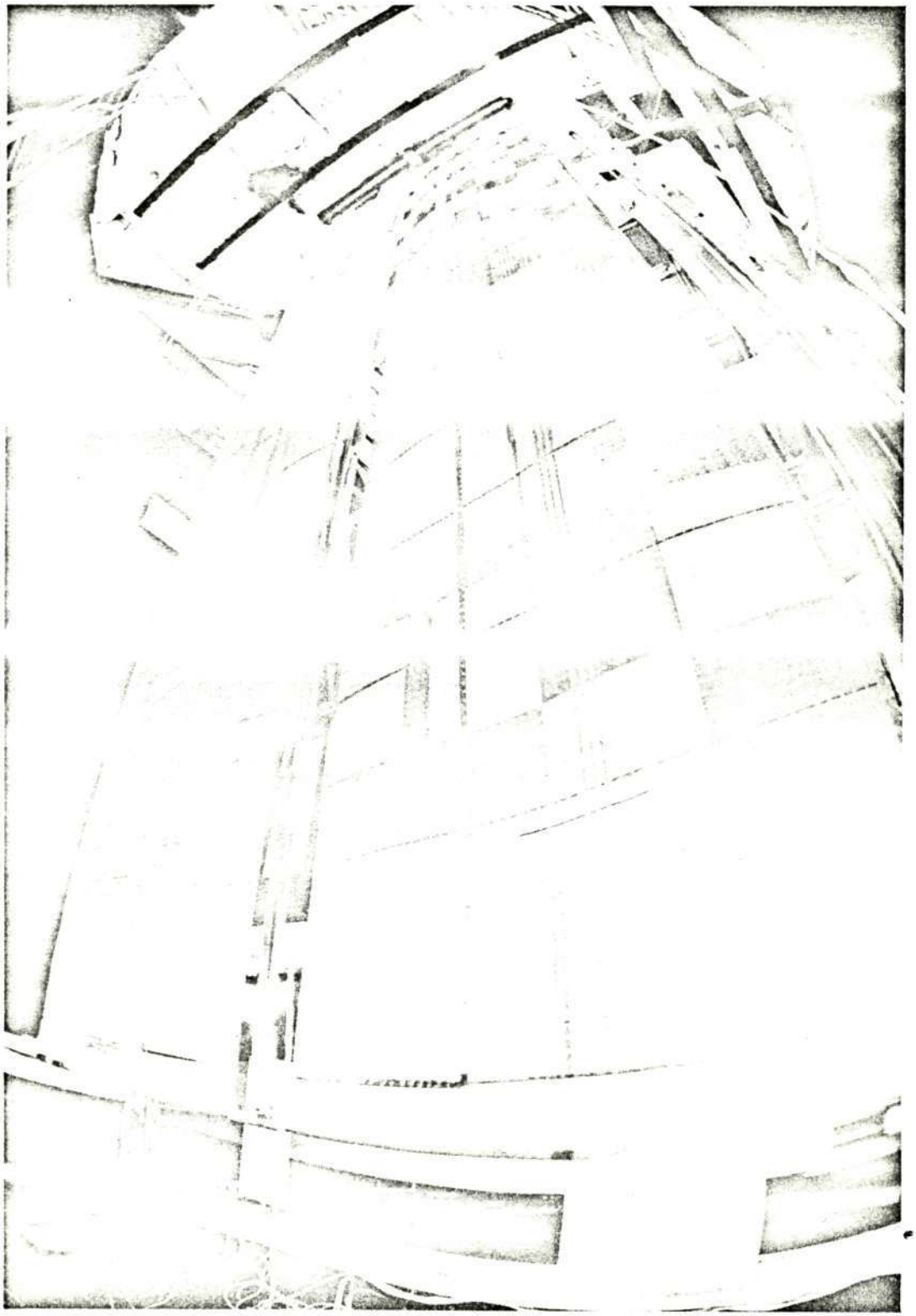


Figure 4.1.2 G. E. Rollup Array - Deployed

TABLE 4.1.3

SUMMARY OF G. E. ROLLUP ARRAY ENVIRONMENTAL TESTS

ENVIRONMENT	LEVEL	TECHNICAL COMMENTS
Pyrotechnic Shock	As generated by array pyrotechnics	
Thermal-Vacuum Tests		
Stowed	$-130^{o}C$ $+140^{o}C$ Thermal shock between $-130^{o}C$ and $140^{o}C$	Requires long dwell time to produce uniform temperature. Selection of control points
Deployed	$-130^{o}C$ $+140^{o}C$ Thermal shock between $130^{o}C$ and $140^{o}C$	Large differences in thermal mass cause large temperature differences in system. Selection of control points
Deployment	Low temp ($-130^{o}C$) High temp ($140^{o}C$)	Long dwell times to produce uniform temperatures Selection of control points. Deployment in 1 G requires support fixture.
Acoustic Noise	150 dB overall spectrum specified	
Vibration		
Sinusoidal	5 - 10 Hz 0.90 in DA 10 - 225 Hz 4.6 g's (O-P) 225 - 550 Hz 0.00176 in DA 555 - 2000 Hz 27 g's (O-P)	Three widely spaced support points
Random	90 - 700 Hz $1\ G^2/Hz$ 20 - 90 Hz Increasing at 6 dB/ octave 700 - 2000 Hz Decreasing at 6 dB/ octave	Three widely separated support points
Mechanical Shock	250 G, 0.5 millisecond terminal sawtooth	Large mass of test unit imposes extreme demands on vibration equipment

TABLE 4.1.4

SUMMARY OF G. E. ROLLUP ARRAY PERFORMANCE TESTS

TEST	TECHNICAL COMMENTS
Deployment/Retraction	External support required for 1 G operation. Need to minimize tracking restraints.
Electrical Performance	Large area involved. Solar simulation desired.
Chip and Crack Inspection	Large area and large number of units involved.
Deployed Thermal Bending	Realistic test conditions involve large area illumination, gravity effects, and thermal environment.
Deployed Dynamics	State of the art testing problem involving low frequency regime, aerodynamic effects, gravity effects, and measurement of blanket motion.
In-Plane Structural Characteristics	Blanket tension forces should exceed gravity forces. Solve problem discovered in deployed dynamics tests.
Wrap Tension for Stability in Vibration	Solve problem discovered in stowed vibration tests.

(B) LMSC Space Station Array Quadrant and Astromast Tests (see Biblio L. 4-56, L. 4-54 and L. 4-52)

A significant portion of this solar array study was devoted to two major hardware ground tests: one to ascertain the load capability and characteristics of the central extendible beam (Astromast) and the other to deploy and retract a full scale mockup of one quadrant of the total system.

(1) "Astromast" Load Tests

The specimen for these tests was the Astromast beam constructed by Astro Research Corporation of Santa Barbara, California. It is shown in Figure 4.1.3 under Bending Preload test conditions. The Astromast is fully described in LMSC-A995719 (see Biblio L. 4-48) and its specifications are listed in Table 4.1.5. The type of load tests conducted on the Astromast and results are presented in Table 4.1.6. The Astromast is an excellent choice where high strength, low thermal bending, loaded extension and retraction capability are required for a beam.

TABLE 4.1.5
ASTROMAST SPECIFICATIONS

Overall weight	400 pounds
Beam weight (upper 64 bays)	214 pounds
Beam length (upper 64 bays)	84.0 feet
Beam diameter (circle through longeron axes)	20 inches
Canister height	52 inches
Nominal outside diameter of canister (excluding drive motors)	23.75 inches
Outside diameter of attachment flange	26.70 inches
Power	Three 28-volt d.c. electric motors
Average amperage per motor (at 28 volts, resisted by 280)	6 amperes

Figure 4.1.3 Astromast Under Bending-Preload Test

TABLE 4.1.6

ASTROMAST BOOM LOAD TEST SUMMARY

TEST	TEST DESCRIPTION	SPECIMEN PROPERTY	TEST VALUE	CALCULATED VALUE
1. TORSION	The specimen was torqued up to 1500 lbs (300 lb. increments) three times each in clockwise and counter-clockwise directions.	Torsional Stiffness (GJ) $lb\text{-}in^2$	4.6×10^6	2.52×10^6 (Zero tension) 6.57×10^6
2. BENDING/PRELOAD	Moments up to 9000 in-lbs at various axial compression and tip loads up to 1500 lbs. were applied to the specimen for lateral deflection.	Bending Stiffness (EI) $Lb\text{-}In^2$	2.0×10^8	4.7×10^8
3. SHEAR/PRELOAD	Lateral deflections of the specimen by applying tip lateral loads up to 14 lbs (1 lb increments) with various axial compression preloads up to 1500 lbs (300 lb increments)	Shear Stiffness (KAG) Lb.	93,000 (from torsion) Random Results From Shear/Preload	50,400 (zero tension) 126,000 (tension)
4. DAMPING	Tip of specimen deflected manually and allowed to oscillate along Y-Y axis (repeated on Z-Z axis)	Fundamental Bending Frequency (Hz)	0.22 - 0.24 Critical at 0.10	0.40
		Structural Damping Coefficient	7.8% @ 1.7 in. trace ampl. in Y axis 5.4% @ 1.3 in trace ampl. in Z axis	Not estimated
5. STRAIGHTNESS AFTER DEPLOYMENT	The specimen was fully deployed 3 times. Tip and longeron deviations measured by tip scales and transits	Max Tip Deviation	4.05 in.	Not estimated
		Max Tip Rotation	2° 36'	
		Max Longeron Deviation in 84'	0.88 in.	
6. BENDING AND SHEAR/PRELOAD	Deflectometers located at the base (deployment canister) yielded data from Test (2) and (3) above.	Support Stiffness	0.9×10^5 lb-in axial 0.82×10^7 lb in rad bending	Not estimated

(2) Space Station Array Quadrant (2500 ft^2) Deployment/Retraction Tests

To prove feasibility of large area array design, fabrication and test, an array quadrant mockup incorporating the major elements of a 10,000 ft^2 array, was subjected to a series of operational tests.

To demonstrate the quadrant operation it was necessary to counterbalance all deployed fixed and variable weights and to balance the system tensions with an applied but variable moment at the beam cap. This setup was accomplished as shown in Figure 4.1.6.

A 40 ft "I" beam was supported from the test area ceiling which was 110 feet above the floor and stabilized by a cable on each end tied to the floor. It was used to support the pulley systems for the deployed variable and fixed weights. Chains of various weights per meter in combination with fixed weights were used as the variable counterbalances.

A moment reaction beam in conjunction with a cable was used to balance the quadrant tensions. The cable was attached to the overhead beam, passed around a pulley near the Extendible Boom System (EBS) cap and over another pulley at the reaction beam tip and then attached to a hydraulic cylinder at floor level.

Figure 4.1.4 is a view of the specimen partially deployed showing all 5 array strips being extended at one time which is the maximum loading for the extendible truss structure. Figures 4.1.5 and 4.1.6 are views from the bottom and top respectively of the fully extended array. The total assembly was extended and retracted from 0 to 85 feet 20 times without a malfunction of any part of the structure, array strip, or packaging mechanism. This is twice the anticipated operation in a 10 year mission.

In addition, two cycles were accomplished demonstrating the ability of the array system to extend and retract a single strip for replacement or additional power. During any extension or retraction the air conditioning was shut down to assure that no excessive wind loads were imparted to the array.

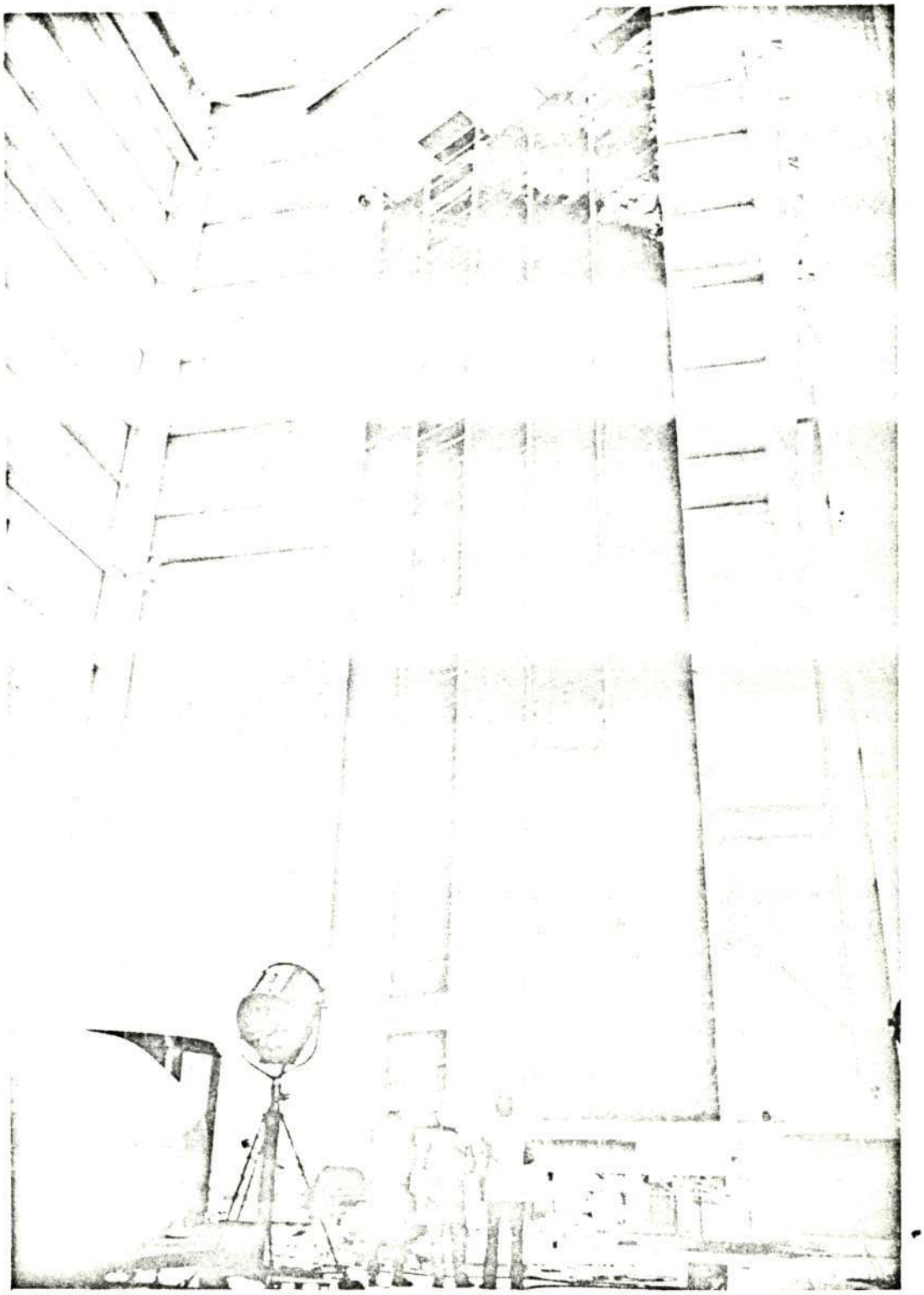


Figure 4.1.4 Array Quadrant - Fully Deployed

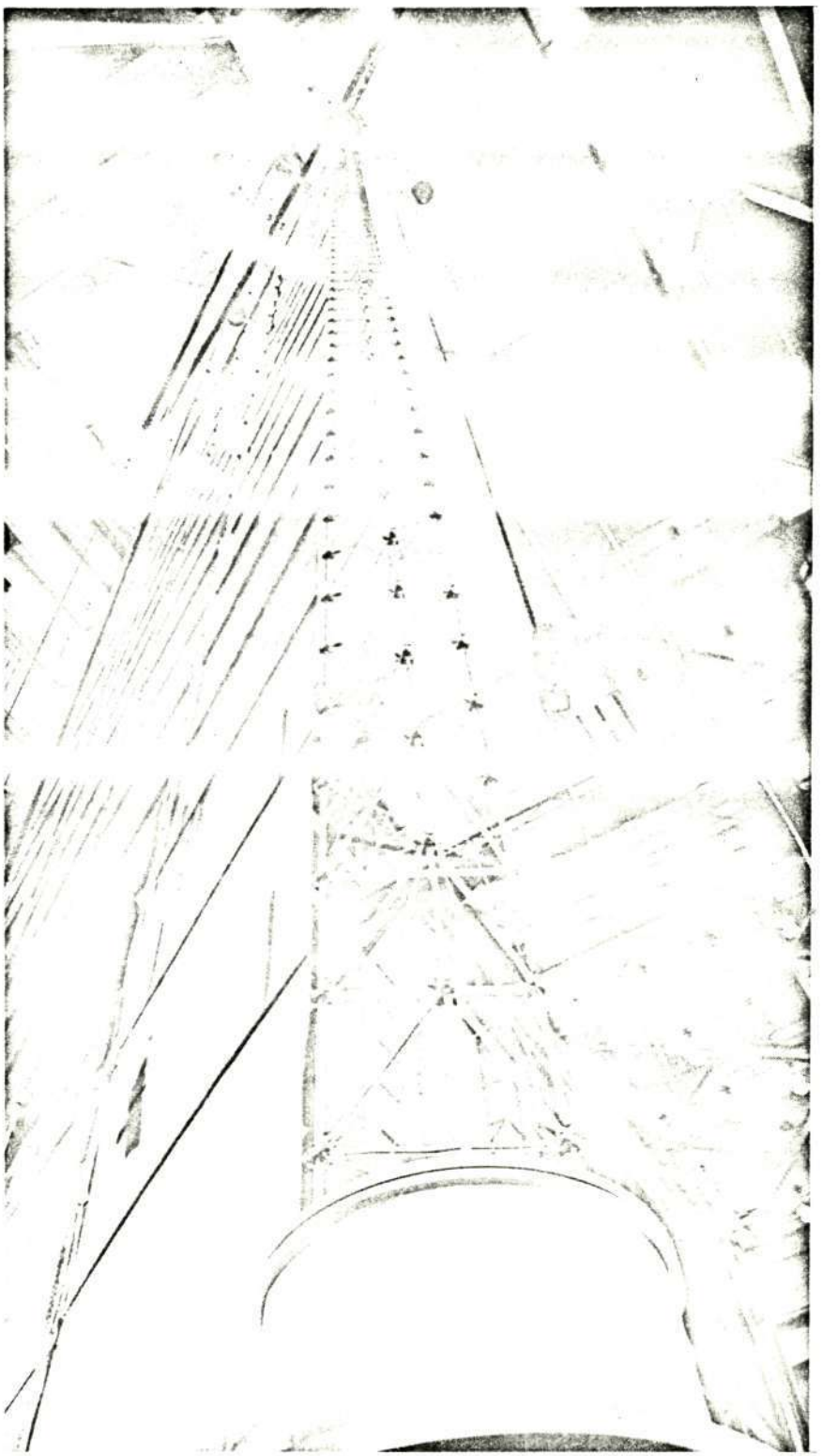


Figure 4.1.5 Array Quadrant - Bottom Along Astromast

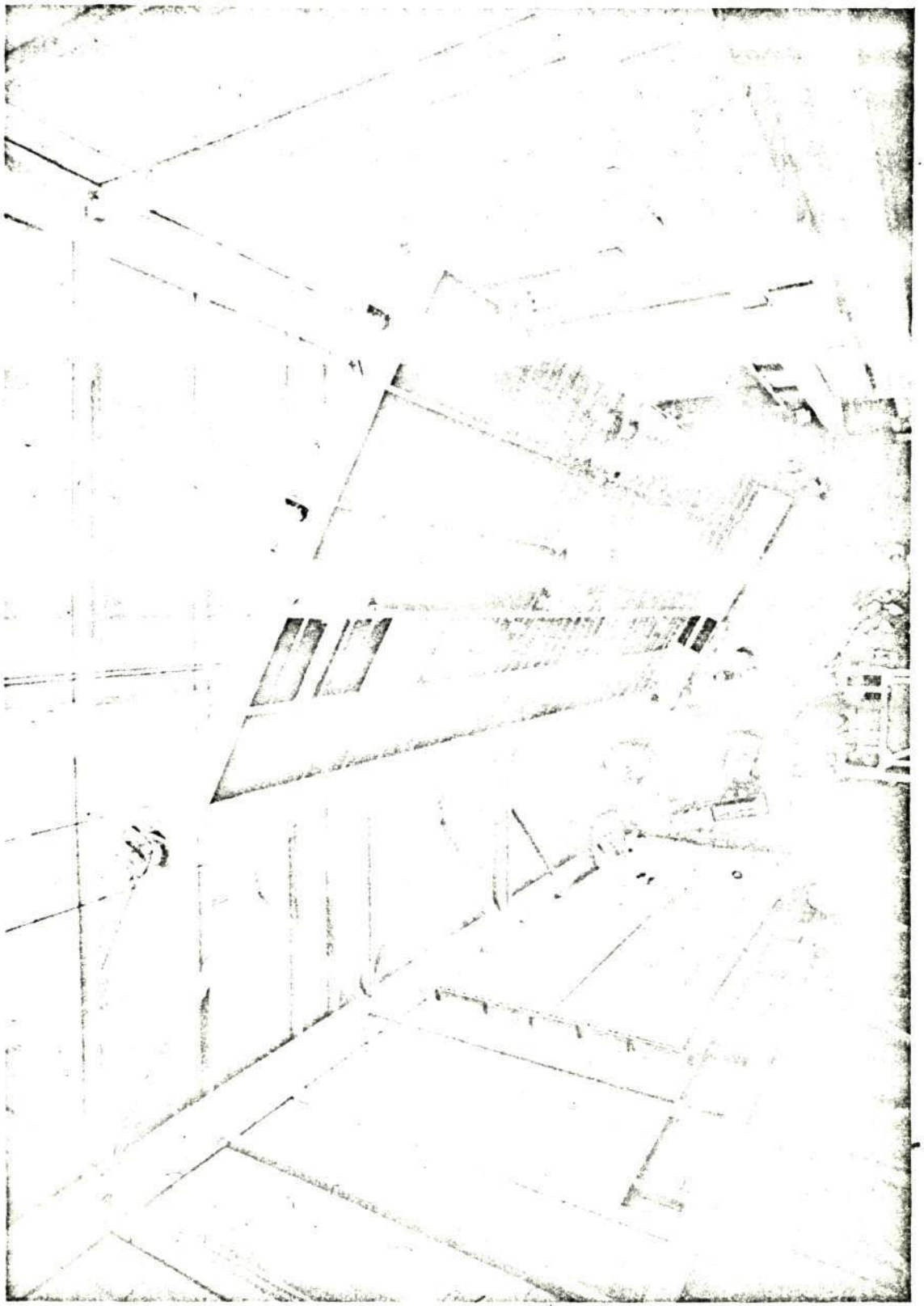


Figure 4.1.6 Array Quadrant - Top View

Details of all design support and major hardware tests conducted under the Space Station Solar Array Technology Evaluation Program are presented in LMSC/D153526 (see Bibliography L. 4-56). In conclusion it can be stated that vertical testing of large area flexible substrate arrays is a practical method of ground testing if adequate indoor facilities are available.

(3) Hughes Aircraft RTD-806 Solar Array Flight Test

Under this program, initiated by the Air Force (AFAPL Wright-Patterson, Dayton, Ohio) in July 1968, a lightweight flexible retractable 1.5 KW solar array was designed and fabricated for an eventual feasibility space flight aboard the SESP (STP) 71-2 vehicle. In September of 1971 the flight system, after completion of development, acceptance, and qualification tests was installed aboard the Agena spacecraft. The unit is shown in Figures 4.1.7 and 4.1.8 undergoing a RF Radiation Susceptibility Test in an LMSC Anechoic Chamber. The RTD-806 flight unit was successfully launched aboard the Agena in October 1971.

The FRUSA (Flexible Rolled-Up Solar Array) presently on the Space Test Program (STP) 71-2 vehicle has been in operation since its launch in October 1971. At orbit 10, the array was initially deployed from a common drum as depicted in an artist's view of the spacecraft in flight, Figure 4.1.9. After reaching full deployment, the panel tip accelerometers experienced no significant variation, thereby indicating that the panels were dynamically quiet. Table 4.1.7 shows the full mission operations of the mechanical system. Figure 4.1.10 shows IV curves of the solar array power output at the peak power point. Both Table 4.1.7 and Figure 4.1.10 indicate achievement of the contractual requirements.

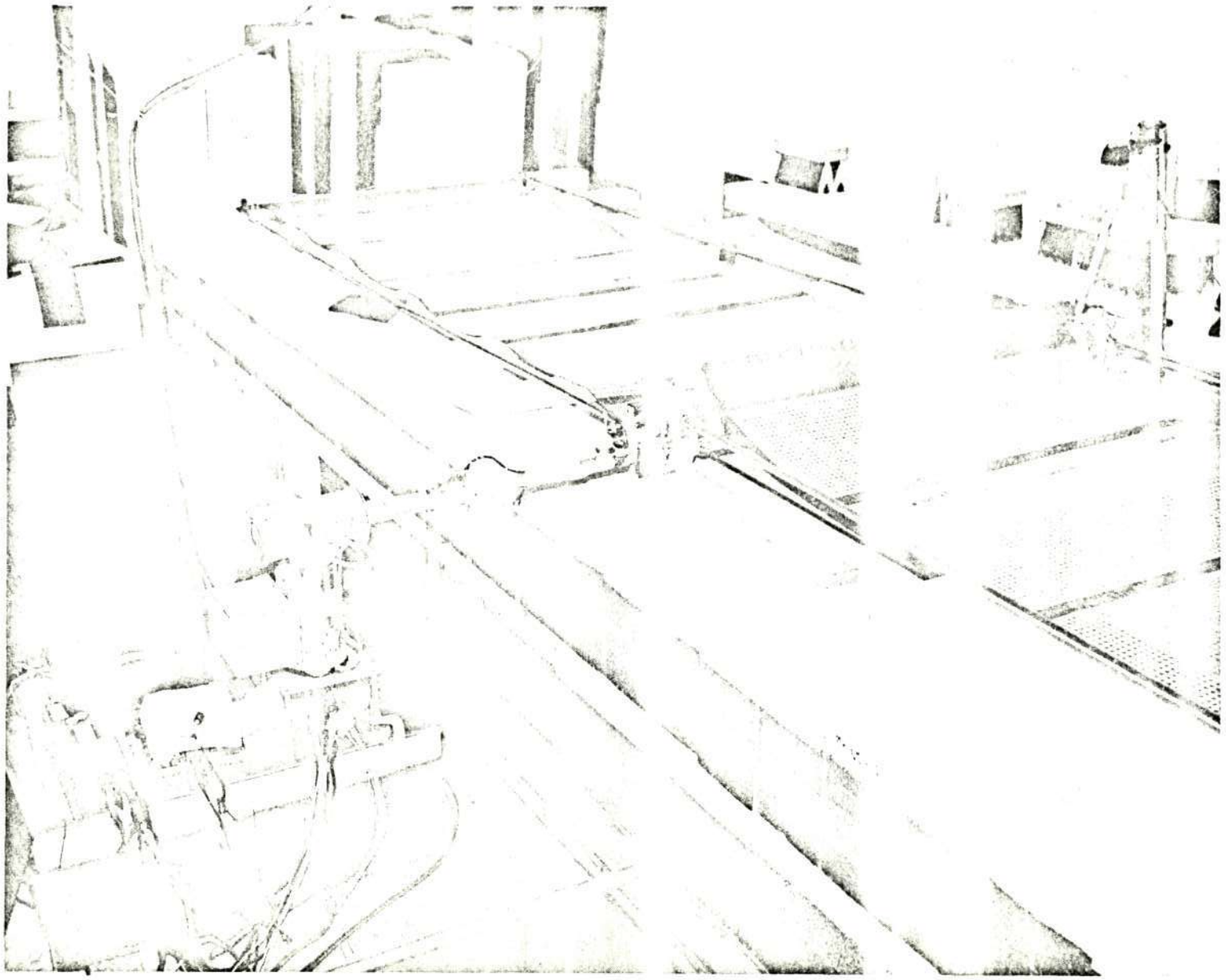


Figure 4.1.7 FRUSA RF Radiation Susceptibility Test

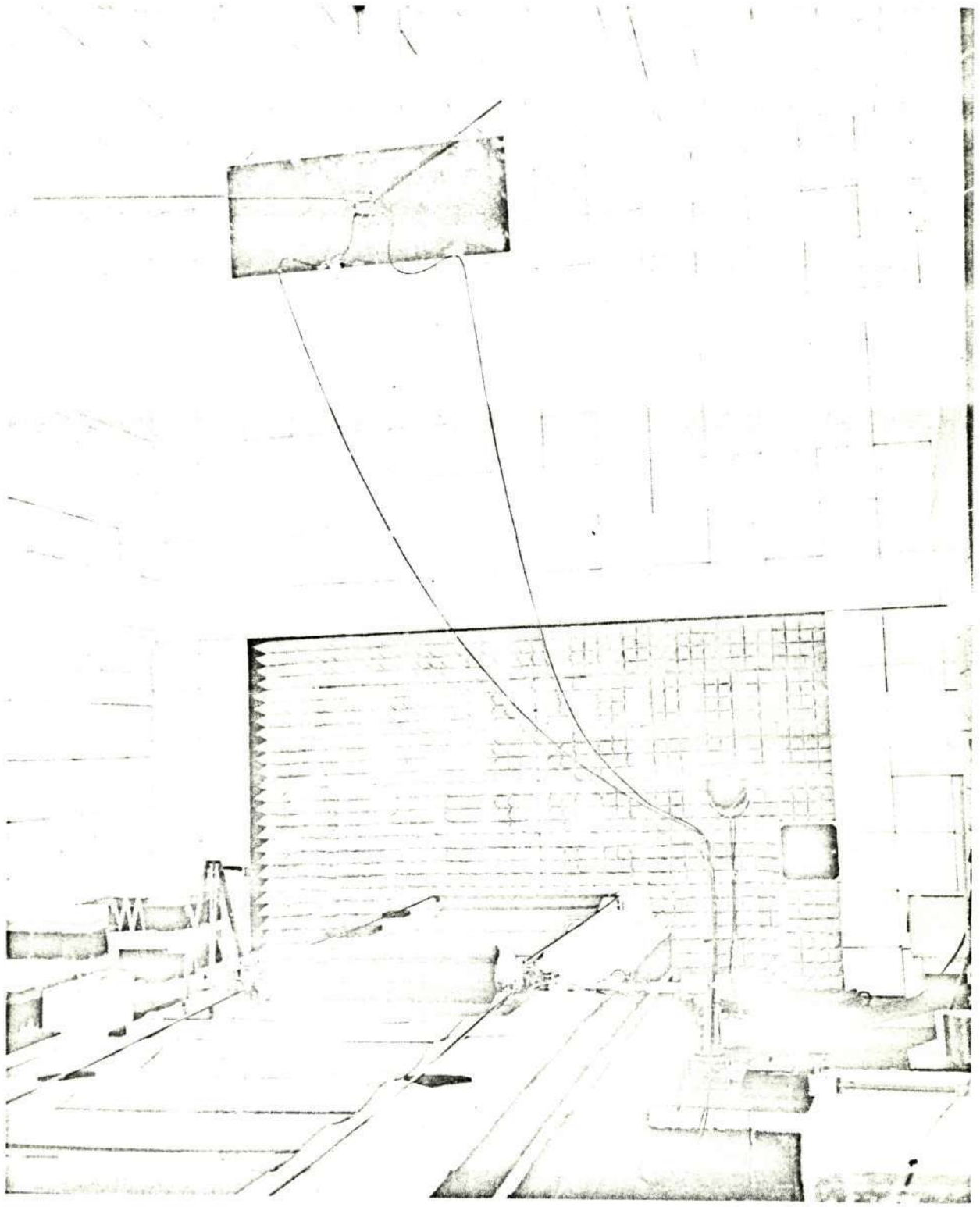


Figure 4.1.8 FRUSA RF Radiation Susceptibility Test

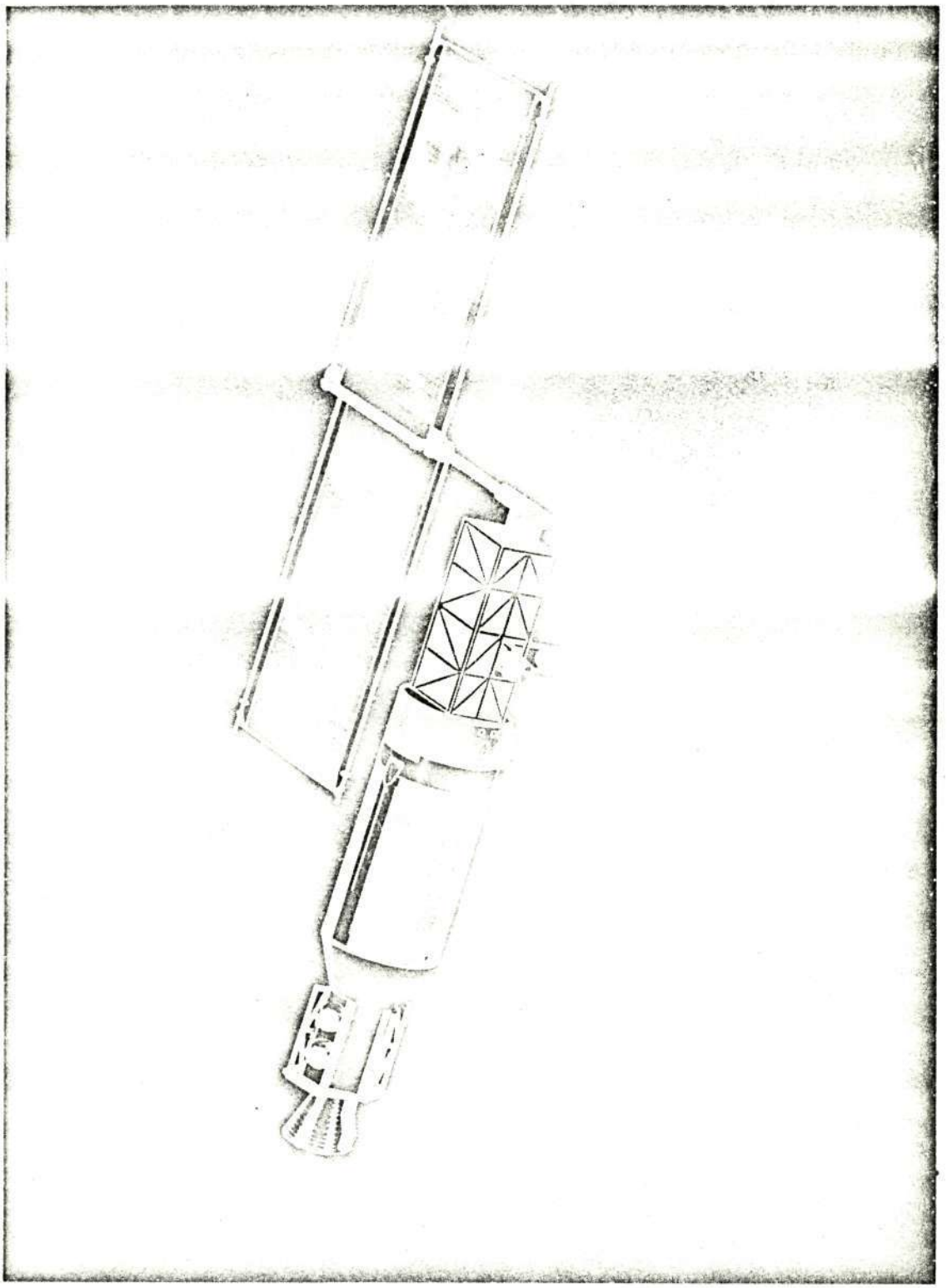


Figure 4.1.9 FRUSA Flight Test - Artist's Conception

TABLE 4.1.7

RTD-806 MISSION OPERATIONS

Operation	Orbit
First status check	2
Pitchdown and FRUSA deployment	8
Extension of FRUSA array panels	9
Sun acquisition	10
Application of FRUSA power to SAMSO-002 bus	10
Retraction of FRUSA panels 1/3 and re-extension	79
Retraction of FRUSA panels 1/6 to reduce SAMSO-002 power	171
Re-extension of panels	621
Retraction and extension of FRUSA panels	936
	947
	948
	949
	950
	1136
	1137
	1138
	1143
	1144

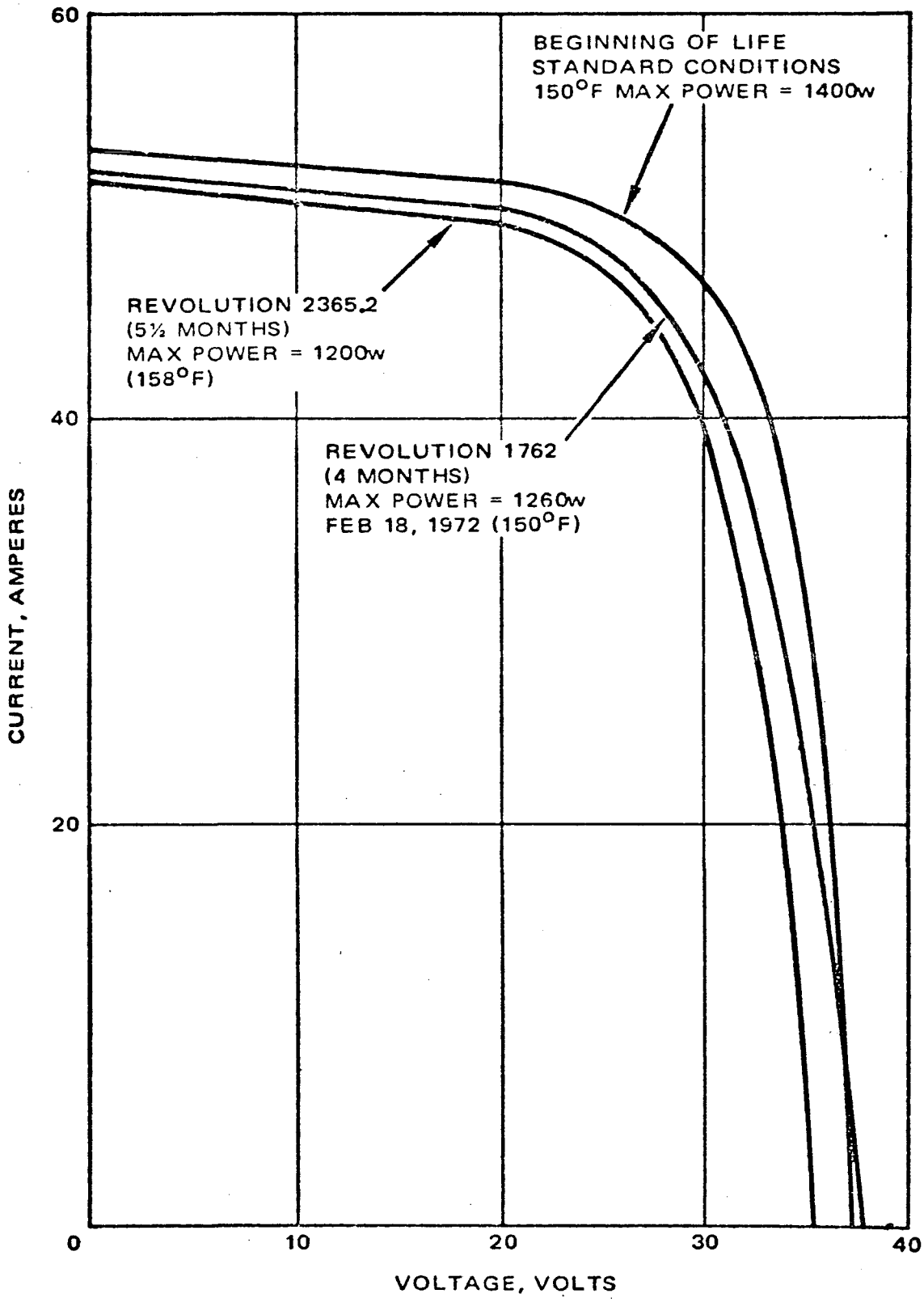


Figure 4.1.10 FRUSA Power Output Comparison

4.1.1.3 Dynamics Analysis Techniques of Flexible Array Assembly

The reference documents (F.1-13, -14 and -15 Biblio) describe the progress of work performed under NASA contract NAS1-10155 (Fairchild-Hiller for NASA Langley Research Center).

The first program formulated under this contract designated "SASSDYNE 1" incorporated a rigid non-spinning spacecraft and a flexible, fold-out panel array. The modal properties of the flexible array were computed using a finite element program derived by JPL, and those of the fold-out structure by driving a truss type model using rigid beams and elastic cross-braces. Included in the digital simulation were optional space station attitude control systems and considerations of external force applications.

A second program "SASSDYNE II", is described which incorporates significant improvements over "SASSDYNE I" including (1) space station flexibility, (2) the capability to account for up to 4 non-controllable, rigidly attached, flexible appendages to the station, (3) a more detailed reaction jet control system with the capability of accounting for local flexibility of the space station at each jet location, (4) the effects of operating a linear orientation control system on the solar array, (5) a simplified version of a spacecraft control moment gyro, and (6) an improved digital technique whereby all system dynamic equations may be solved simultaneously. In conjunction with this work a comparison is made between modal properties derived using the "NASTRAN" program and a method attributed to K. Gupta of JPL which it is intended to use to determine modal properties of a spinning space station in the continuation of the study contract.

4.1.1.4 Packaging, Extension and Tensioning

Three basic flexible array packaging techniques for space station use were thoroughly described and compared in chart C and the associated text. A fourth conceptual approach (see Biblio I. 6-1) to packaging and extension of large area solar arrays, is added to the old Chart C (Table 4.1.8). Although specifically designed for direct TV broadcasting satellites being considered by West Germany - IBS (Ingenieuburo Scheel), this type of array development claims almost double power to weight ratio and lower cost, by diminishing the structural mass below that claimed for drum roll-up and flat fold arrays being developed in the U.S.

Centrifugal force of a spinning body is used to unfold (deploy) and to stiffen the light weight flexible arrays. The array substrate can be extremely lightweight since no bending or compression stress is experienced which would require heavier rigid structure.

The circular flexible array consisting of multiple submodules is stowed in "meandric" manner and folds on the outer surface of a cylinder. It is compressed there by a highly stressed bandage of Kapton film. For on-orbit release the film is cut by a pyrotechnic device and winds off. Successive layers of the array extend radially in unfolding steps until the large circular solar array is completed. The array could also be parabolic in shape to use its backside as RF-reflector.

Several "unfolding" tests were successfully conducted both in air and vacuum on models up to 7.5 feet in diameter. Substrates of mylar film and polyamide (nylon) cloth were covered with Al-dummy cells on the majority of modules and some connected silicon solar cells were attached to critical areas of some modules. Power to weight ratios of 45-50 watts/lb were achieved for these models.

An artist concept of an independent spinning 200 KW solar generator with attitude control by ion motors is shown in Figure 4.1.11. A power transfer rope is connected to its spin axis by means of a rotating joint employing liquid metal slip rings. This connection is mounted torque-free to the center of gravity of the generator.

TABLE 4.1.8
NEW SOLAR ARRAY PACKAGING METHOD

Number	4
Stowage Method	Central Cylinder
Illustration	
Protective Padding for Solar Cells During Flight and Ground Handling	Unknown
Deployment/Retraction	Full deployment only. Does not retract.
Drum/Spindle End Support	Supported to the central hub which is connected to the vehicle by a "tether string".
Attachment to Structure	Circular solar array of multiple submodules, folded in meandric manner to the outer surface of a cylinder which is attached to the satellite.
Power Transfer	Present state-of-the-art methods are applicable.
Manufacturing Handling	Additional personnel required to fold panels in meandric manner then wrap around cylinder. May be vulnerable to damage. No info available as to method of manufacturing or handling an array size of 384 ft dia. which is mentioned in the report.
Ground Test Handling	Unknown
Effect of Long Term Storage	May affect interconnects because they are folding members when packaged.
Protection from Contamination and Damage	Packaged array is wrapped within a Kapton "bandage". No protection from falling objects.
Loads and Dynamic Effects	Kapton "bandage" squeezes folded array around cylinder to prevent damage from acceleration and vibration loads during launch.

TABLE 4.1.8 (Cont'd)

NEW SOLAR ARRAY PACKAGING METHOD

Thermal	Unless thermally protected, 1. Temp. gradient between the innermost to the outermost panel wraps. 2. Possible outgassing of lub, seals, etc. 3. Thermal distortion of moving parts may occur.
Tie-Down and Release	Packaged array held in place by Kapton "bandage". Pyrotechnically separated, central cylinder rotates and arrays unfold by centrifugal force.
Tension Method	Deployed arrays continually spin and sheet tension is maintained by centrifugal force. No info available if RPM can be varied to change tension.
Stowage Volume (Ft^3)	Unknown
Reliability	Unknown
General Design Comments	Uncertain about cell protection in packaged condition. No mention of a protective pad for the cells. Uncertain about maintaining some distance between deployed array and vehicle. No information available as to manner of performing ground repair.

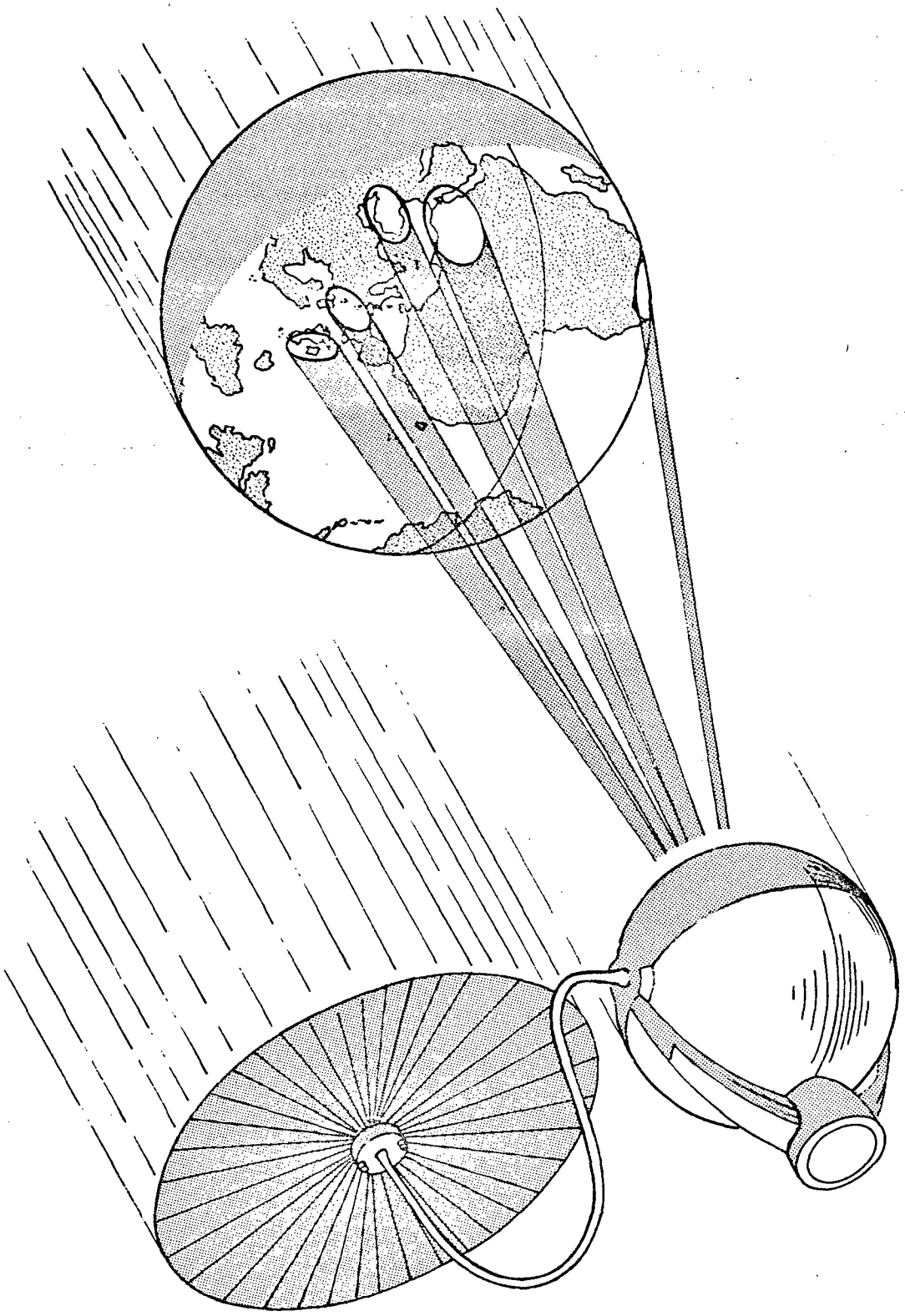


Figure 4.1.11 200 KW Solar Array for TV Space Station

4.1.2 Solar Array Structures

The basic load carrying element in the Space Station Solar Array is the extendible structure or boom. This component is of singular importance since it comprises at least 20 percent of the system weight and is the most difficult portion of the retraction problem.

A brief review was made of one new structural material (4.1.2.1) and of some booms currently in various stages of hardware development or use (4.1.2.2). The information presented in these two sections did not alter the boom comparison in section 4.1.2.3 which was, therefore, left blank intentionally.

4.1.2.1 Structural Material Candidates

Chart D of the Blue Book report (LMSC/A981486) listed ambient physical characteristics of 10 candidate materials, along with present and predicted costs and producibility. In the interval, only one other material PRD -49* (polymeric synthetic fiber) was found worthy of reporting. The characteristics of this composite reinforcement of unusually high strength and modulus are presented in Table 4.1.9.

Epoxy composites fabricated with PRD-49-I have exhibited good unidirectional static and fatigue tensile properties. Unidirectional composite compressive properties are low (around 40-50 x 10^3 psia, 60% volume fraction) and thought to be due to the high degree of fiber anisotropy.

TABLE 4.1.9
STRUCTURAL MATERIAL PROPERTIES

	Density Lb/in^3	F_{tu} (KSI)	F_{cu} (KSI)	E_t ($x10^6$psi)	E_c ($x10^6$psi)	E_t/e ($x10^6 \frac{psi}{lbs/in^3}$)	Coeff of Therm exp 10^{-6}in/in/°F Long	Transv	Vapor Press @10^{-8} Mill of Hg, KELV	Material Cost/Lb 1970	1972	Cost/in^3 1970	1972	Producibility Rating
PRD-49 Fiber Epoxy (Dupont Fiber)	.050	210	45	12	12	240	-2.8	2.0	*		50		2.5	3.5

*High Performance Reinforcements for Advanced Structural Composites. (Fibers: Special Issue on Composites - SAMPE (Society of Aerospace Materials & Process Engineers, Vol II No. 2, June 1972)

4.1.2.2 Deployment/Retraction Structures Review

The total field of current extendible structure technology was thoroughly reviewed in the First Topical Report (LMSC A981486 Biblio L. 4-47). Basic characteristics of all possible methods of deployment, stowage, and packaging were compared in Sections 4.1.2.2 and 4.1.2.3. It is the sole purpose of this section to present several unique methods of deployment and packaging systems being developed as possible candidates for use on future manned spacecraft of the shuttle-launched-type missions. Only those which are or could be applied to flexible solar arrays are considered here.

Only extendible structures numbers 8 (Astromast Articulated Lattice), 12 (Lenticular Welded Beam), and 16 (Extendible Reel Stored) from LMSC A981486 (L. 4-47) - Chart J have been redesigned or updated. The new information for these three extendible structures is summarized in Table 4.1.10.

The Astromast (#8) was selected for the Space Station Baseline Design (see Biblio L. 4-48) , was designed and fabricated in 1971, and was tested at LMSC (see Biblio L. 4-56) in early 1972. Load testing of the Astromast is discussed earlier in Section 4.1.1.2 of this report. The Astromast is shown in Figure 4.1.12 fully deployed during Acceptance Test.

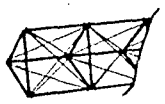
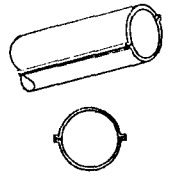
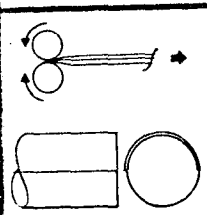
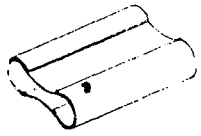
Characteristics of other types of existing Astromasts used in various terrestrial and space application are given in Table 4.1.11.

A private communication was the only available information on the Celesco Sampler Boom (#12) shown in Figures 4.1.13 and 4.1.14. Two prototype units will be delivered to Martin-Marietta in mid 1972.

The Fairchild film transfer boom to be used on Skylab I is shown partially extended in Figure 4.1.14(a). Three units were fabricated and delivered to NASA Huntsville for underwater astronaut training.

TABLE 4.1.10

UPDATED DEPLOYABLE STRUCTURES SURVEYED

No. and Name of Extendible Structure	Illustration	Description & Operation of Structure & Mechanism (Retraction Capabilities	Flight Experience	Source	Development Work	General Design Comments	Producibility	Lifting and Ground Deployment Demo. Environmental Testing Static Load Testing	Handling Installation on Spacecraft	Bibliography and Vendor Data
8 Astromast Articulated Lattice			None	Astro Research Corp., Santa Barbara, Calif.	Full scale 84.0' long motorized boom built and demonstrated for use with large area (5000 ft^2) flex solar array. Deployed and retracted 18 times	Excellent packaging factor. Drive motors very accessible. Compared to other deployable structures, this boom has excellent stiffness to weight ratio. Boom is at full strength during deployment. Essentially free of thermal distortions (replaces old)		Dozens of ground deployment/ retractions without failure		
12 Lenticular Welded Beam		Drum would ribbon of two layers (stainless foil) welded at the edges. As boom unwinds from drum tension stresses suppressed in the flattened cross section are freed. Boom assumes slightly ovate, rounded cross section. Permanent magnet drive motor and gear train for each axis. Extend/retract; azimuth and elevation.	Will operate from Viking 75 Mass Lander	CELESCO Industries, Costa Mesa Calif. (was Atlantic Research Syst. Div.)	Viking Lander surface Sampler Boom extended up to about 10'-0, designed to exert 30 lb. digging force at its tip in order to penetrate Martin sail	Internal flat electrical cable provided paths for commanding and sensing digging functions. Retracted boom assy. is 13.5" high, 9.2" wide and 24.2" long including the shroud. Weighs less than 21 lbs.	Carpenter Custom Stainless 455 thin steel foil, welded at edges to form a closed section		Unknown	Communication to LMSC 6-6-72
16 Extendible Reel Stored			Apollo 15, 16 & 17 Extensions for mass & gamma-ray spectrometers and for "lunar sounder"	SPAR Aerospace Products, Ltd., Ontario, Canada					Stowed in the SIM (Scientific Instrument Module)	Communication to LMSC 6-10-72
16 Extendible Reel Stored		Double shotgun boom - two elements, one nested within the other. D.C. motor and gear driven for extension/ retraction. Gear box can be operated manually	Will be flown in 1973 on Skylab I Transfer film cassettes between ATM & Airlock	Fairchild Space & Electronic Div., Germantown, Md.	Astronaut underwater training units (3)	Extends to approx. 30 feet Stores in housing - 20 x 15 x 15 in. Total weight - 90 lbs.	Stainless Steel .008 in. guage 2 in. diameter double barrel	Series of ground and underwater extensions & retractions without failure		Communication to LMSC 7-20-72

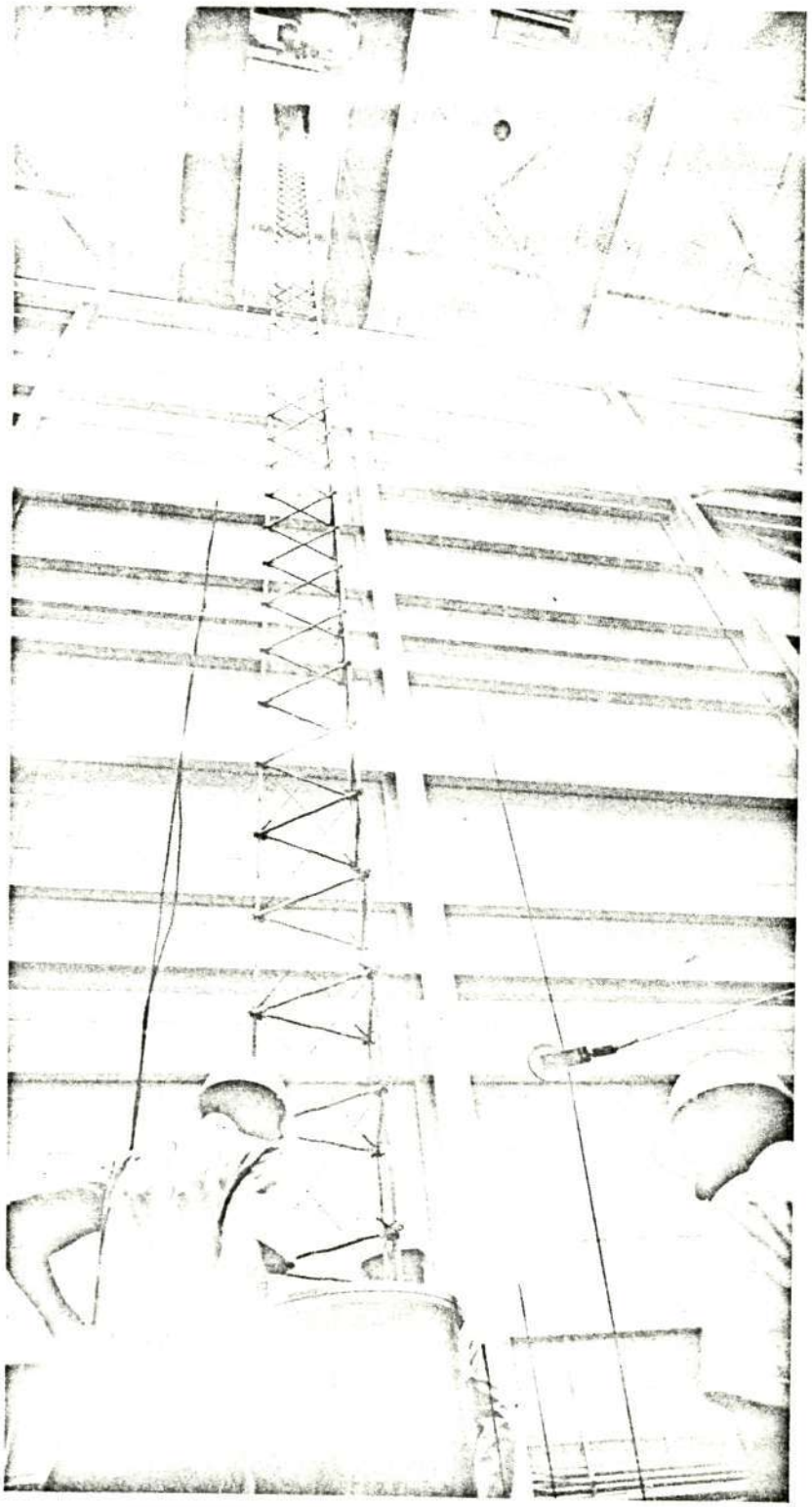


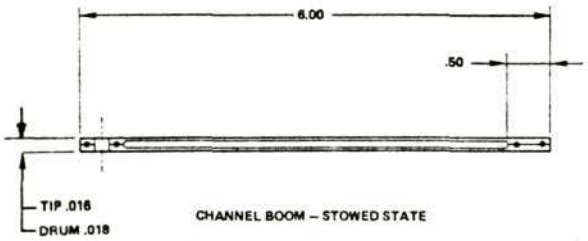
Figure 4.1.12 Astromast Acceptance Test (Fully Deployed)

TABLE 4.1.11

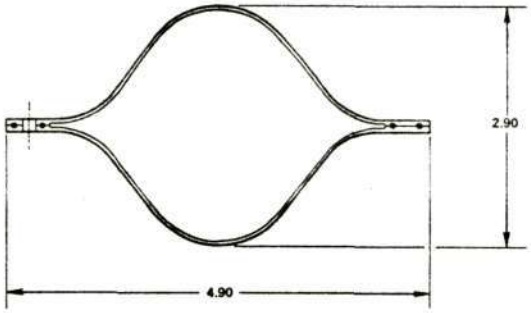
CHARACTERISTICS OF EXISTING ASTROMASTS

Application	Antenna Support Jeep Mounted (Prototype)	Erector/ Support for S/C Helical Antennae	Central Support for Parabolic Mesh Antenna (Subscale Model)	Antenna Support for use on Lunar Surface (Eng. Model)	Support for Space Station Solar Cell Array (Eng. Model)	Support Boom for Antennae of Orbiting Interferometer (Test Segment)
Mast type	Articulated longeron	Continuous longeron	Continuous longeron	Continuous longeron	Articulated longeron	Continuous longeron
Mast diam (in.)	13.4	4	6	10	20	8
Mast length (ft)	40	15	8	100	84	10 (1)
Approx weight Mast (lb)	46	0.30	2.0	20	214	1.3
Canister (2) (lb)	128	(3)	20	30	186	(3)
Package size (4)	25 x 43	4.25 x 6 (5)	7 x 20	11 x 42	24 x 52	8.5 x 4 (5)
Motors	1-1/4 hp 28 V DC	None	1-Globe 28 V DC	2-Globe 28 V DC	3-12 amp 28 V DC	None
Extension rate	1 ft/sec	--	4 in./sec	2 in./sec	2.5 in./sec	--
Bending stiffness ($lb\text{-}in.^2$) x 10^{-6}	77	0.12	0.70	5.5	280	2.04
Bending strength (in.-lb)	7800	25	80	460	36,000	200

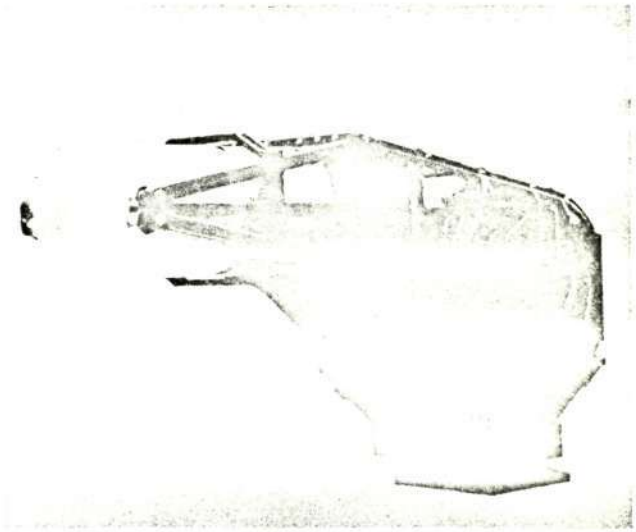
(1) 10 ft test segment of 125 ft required length
(2) No significant effort made to minimize canister weight
(3) No canister supplied
(4) Cylindrical volume - cyl. diam (in.) x cyl. height (in.)
(5) Size of retracted boom alone - no canister supplied



CHANNEL BOOM – STOWED STATE



CHANNEL BOOM – FREE STATE



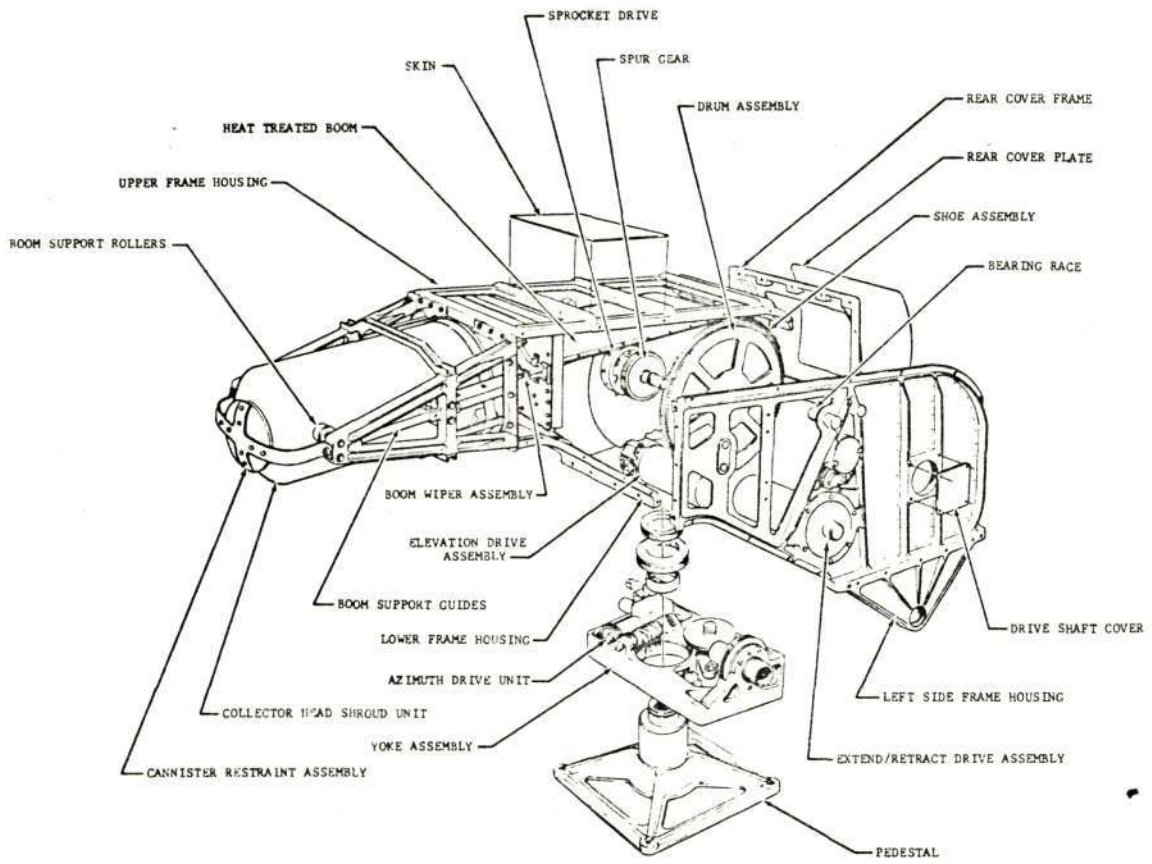


Figure 4.1.13 CELESCO Sampler Boom (Stowed)

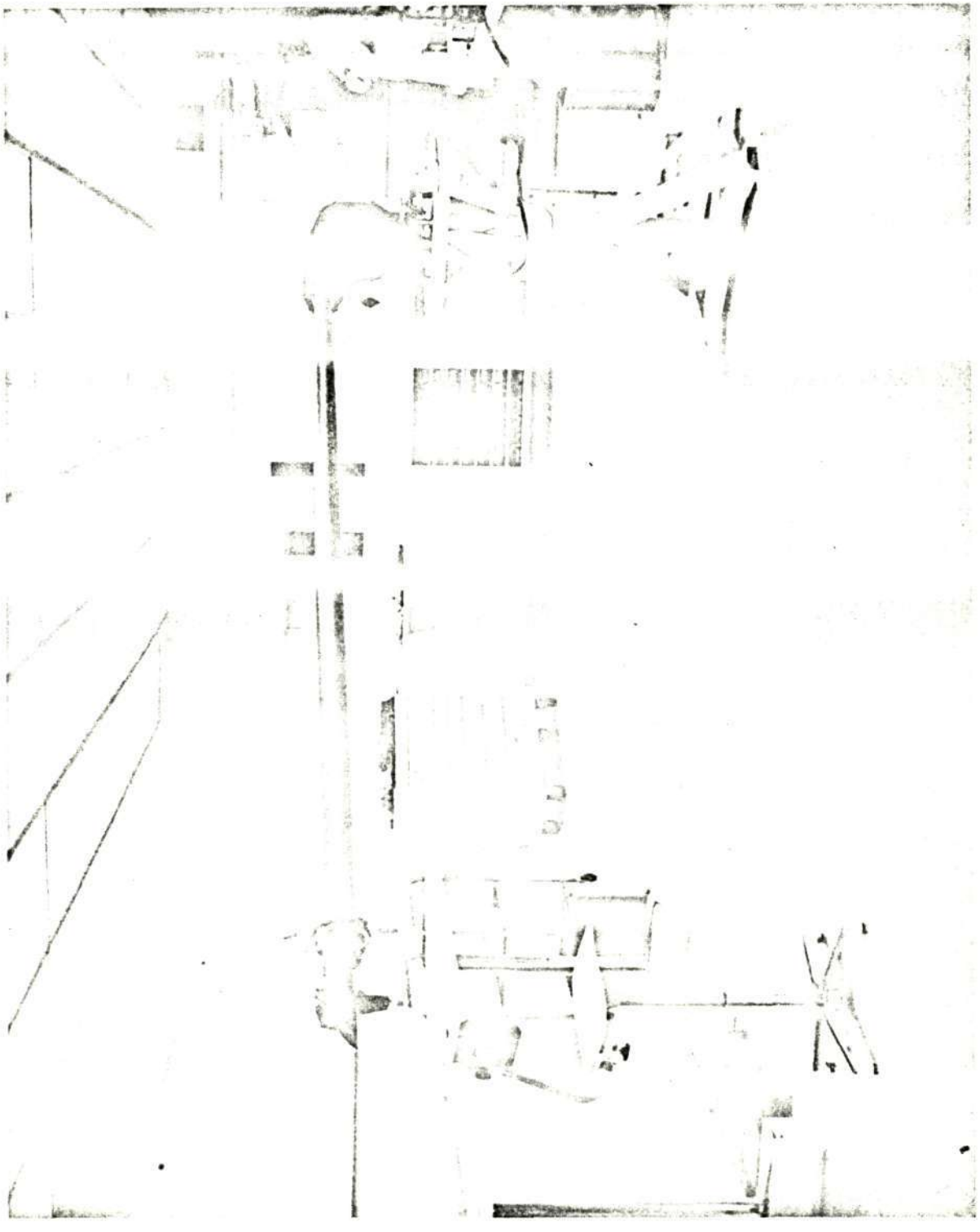


Figure 4.1.14 CELESCO Sampler Boom (Extended)

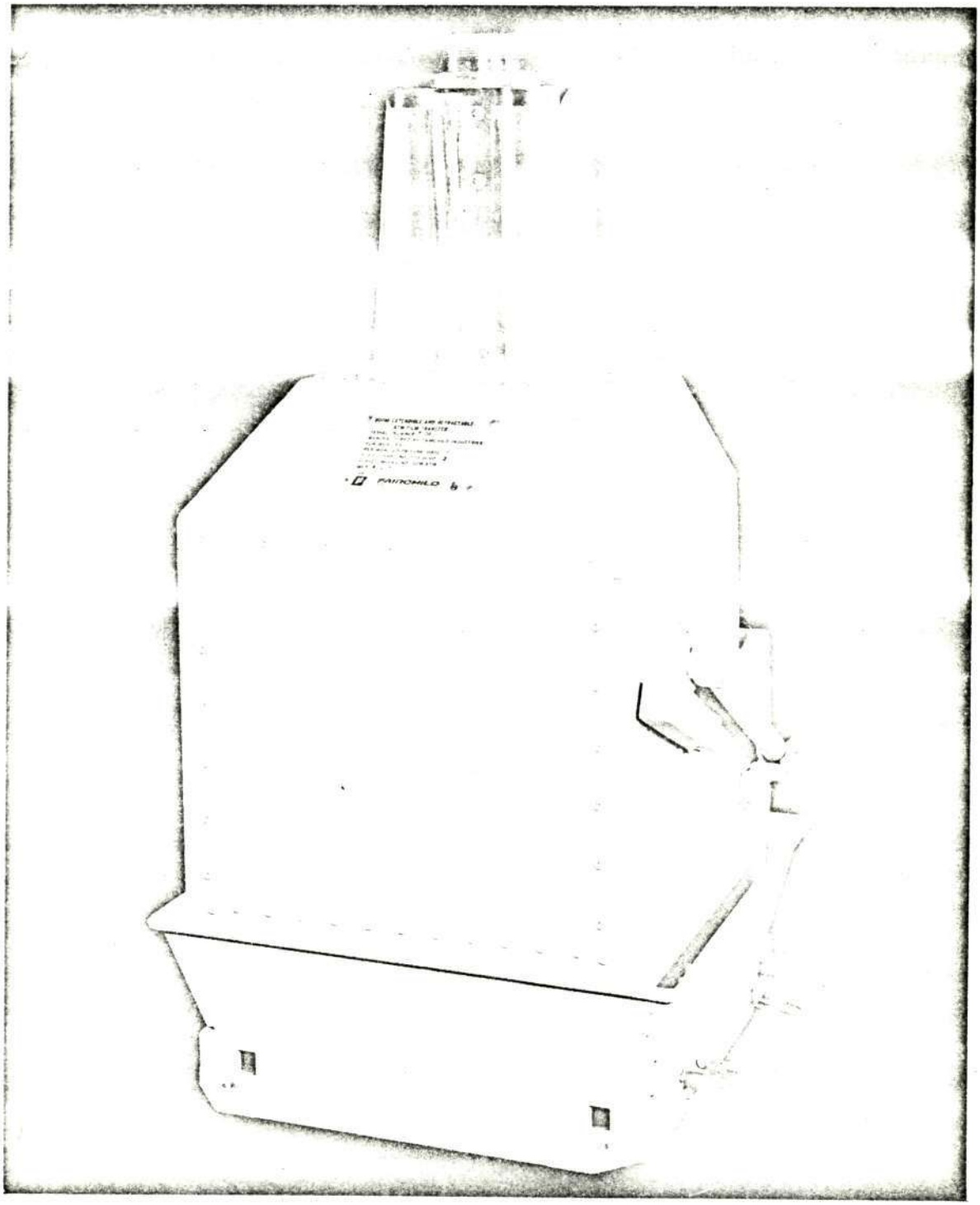


Figure 4.1.14(a) Fairchild "Double Shotgun Skylab I Cassette Transfer Boom

The prototype units will be followed by a development and five flight-configured units by September 1973.

The Spar Bi-Stem type booms used on Apollo 15, 16 and 17 flights were fully described and compared to other types in the original Topical Report (L. 4-47). Since that time two such booms have been flown in so-called Apollo J-missions. One serves to extend the Mass Spectrometer, the other to extend the Gamma-Ray Spectrometer, both from the SIM (Scientific Instrumentation Bay) of the Service Module, as shown in Figure 4.1.15. The mass spectrometer measures atmospheric composition and density and the gamma-ray spectrometer conducts a mapping of the radioactive sources on the surface of the moon. Both spectrometers are extended 25 ft. from the SIM to avoid contaminating effects from the Command & Service Module spacecraft.

A third experiment called the "lunar sounder" will be flown on Apollo 17. It is an HF and VHF pair of antennas which consist of extendible Bi-Stem dipoles of 80 foot span, which swing into position from the back end of the Service Module (see Figure 4.1.16). Characteristics of other SPAR Aerospace Extendible Booms used in various space applications are summarized in Table 4.1.12.

In the event that the modular space stations (RAM's, etc.) would require less than 4,000 ft^2 of solar array (or less than 40 ft extendible beam), the SPAR Bi-Stem booms would be competitive in weight and stowage volume with the Astromast type of boom.

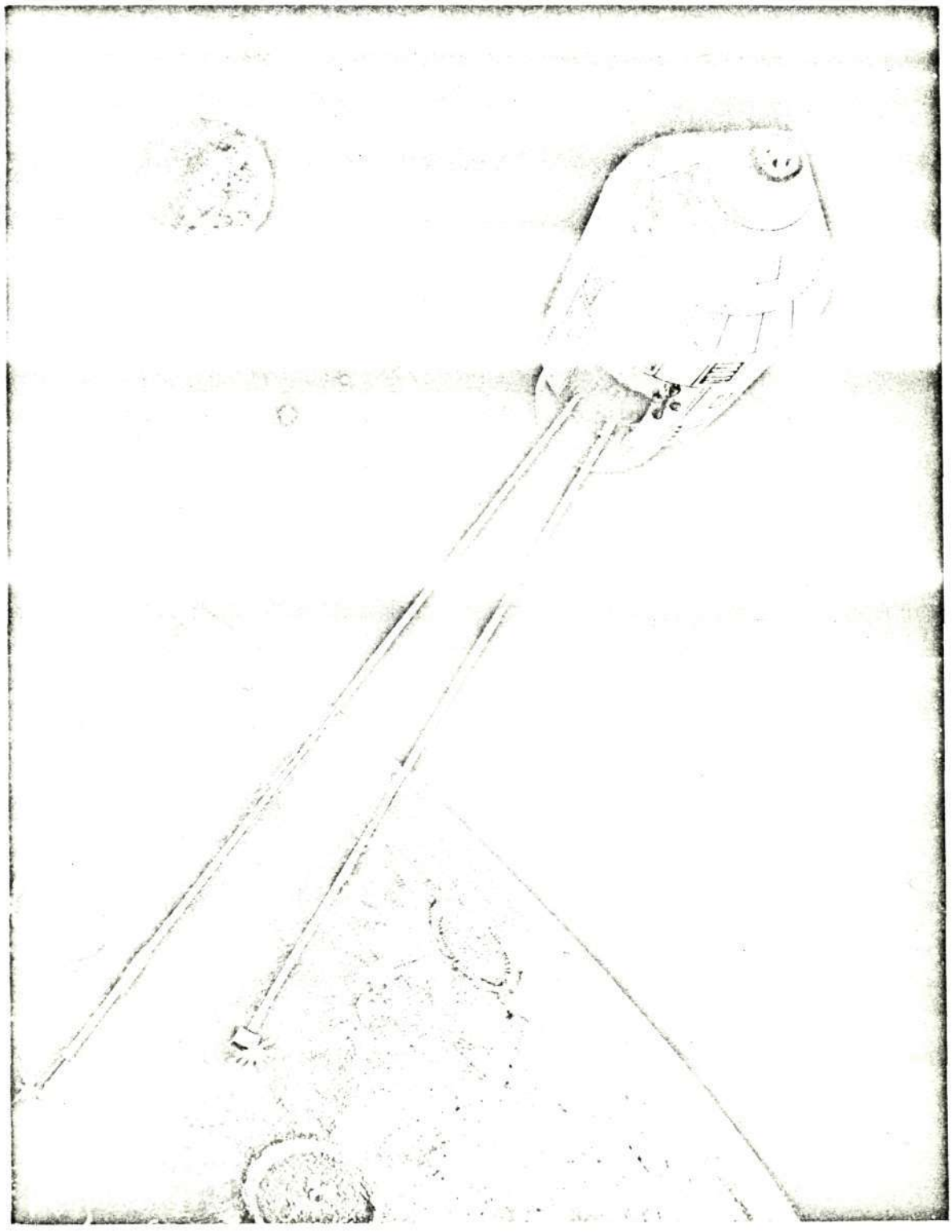


Figure 4.1.15 SPAR - Bi-Stem on Apollo 15 and 16
(Artist's Conception)

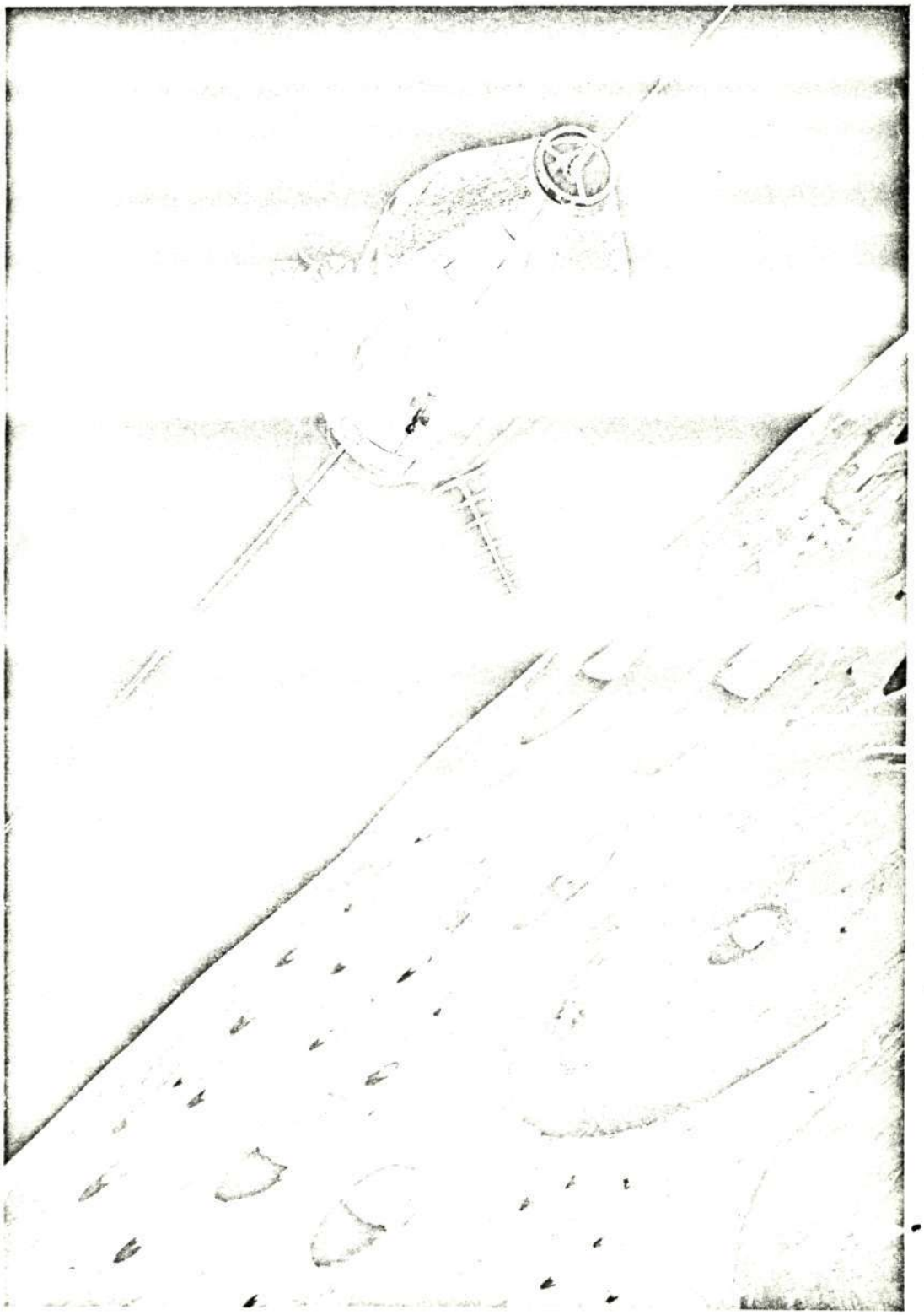


Figure 4.1.16 SPAR - Lunar Sounder, Apollo 17
(Artist's Conception)

B

TABLE 4.1.12

SPAR AEROSPACE EXTENDIBLE BOOMS

Program	FRUSA	Apollo 15/16 Mass Spectrometer	15/16 Gamma Ray	Apollo 17 Lunar Sounder	AEG-Telefunken	NASA-Langley
Type	Bi-Stem	Bi-Stem	Bi-Stem	Bi-Stem	Bi-Stem	MTS Boom
Diameter	.86 in	2.0	2.0	1.34	.86	.86
Element Length	16.0 ft	25.0 ft	27.0 ft	34.0 ft^2	16.0 ft	11.0 ft
Mechanism Size	4.0x11.OD	10.ODx73.5L	10.Dx18.0L	7.5"x8.0"x14.5"	16.0x6.0x4.0	5.0x16.0x4.0
Mechanism Weight	17.0 Lb	57.0 Lb	45.0 Lb	22.5 Lb	16.0 Lb	12.0 Lb
Element Material	301 S.S.	455 S.S.	455 S.S.	455 S.S.	301 S.S.	301 S.S.
Thermal Coating	Silver Plate	Silver Plate	Silver Plate		No Coating	No Coating
Motor Type	DC Motor	2 Motors DC	2 Motors DC	DC Motor	DC Motor	DC Motor
Extension Rate	1/2"/sec	1.8"/sec	1.8"/sec	6.0"/sec	1.6"/sec	7.3"/sec
Number of Boom(s)/ Mech.	2	1	1	2	2	4
Element Thickness	.005	.012	.012	.007	.005	.005
Number of Units (Production)	2	3	3	4	1	1

4.1.2.3 Evaluation of Deployable Structures

The information obtained during this update did not affect the results or conclusions of the evaluation in the original "Blue Book" and therefore the evaluation will not be repeated here.

4.1.3 Solar Array Flexible Substrate Assembly

This section covers the technology review of new data on flexible array assemblies from the available reports and manufacturers data sheets, technical conferences, and personal contacts.

During the interim period, the number of documents covering solar cell development and tests far exceeded all other facets of flexible array technology. This is also partially true of thermal cycling tests of flexible array models. Therefore, Sections 4.1.3.3 and 4.1.3.8 received major emphasis.

4.1.3.1 Candidate Substrate Materials

The ten (10) or so new reports and articles on this subject matter that were reviewed did not reveal any additional material(s) for laminated flexible substrates. Chart M in the First Topical Report (L.4-47) remains current. Items 3 and 4 in that chart (Aclar and Nomex) have too many limitations for Space Station solar array applications and should be eliminated as candidates.

An attempt was made to investigate substrate materials laminating processes but all industrial firms which were contacted considered this to be highly company proprietary and would not release the information. This subject matter which would have been included in this section was therefore dropped from the Technology Evaluation report.

4.1.3.2 Interconnectors

Flexible Solar Array interconnector materials information additional to that presented in Tables 4-2, 4-3 and 4-6 of the original Topical Report are as follows:

4.1.3.2.1 Interconnector Materials

1) Tables 4-2 (Molybdenum) and 4-6 (Kovar) (comment applies to both)

Source:	Comments	Bib. No.
Hughes Aircraft Co.	"There is a serious lack of materials properties at low temperatures which are needed to perform meaningful stress analysis"	N.4-31

2) Table 4-2 (Molybdenum)

Source:	Comments	Bib. No.
EOS	S-shaped interconnects of silver-plated moly withstood 212 LN_2 dips or about 1000 cycles between +71.1 and -73.3°C with a 90 minute cycle.	N.4-31

3) Table 4-3 (Copper)

Source:	Comments	Bib. No.
Olin Brass, Olin Corp.	A new finish is provided on their wrought copper foils which improves band strengths to polyimide films (up to 4.5 lbs peel strength per inch). The new finish is a proprietary morganic film only 4×10^{-7} inch thick (100 Angstrom units). Finish is stable up to 400°C (752°F), therefore does not interfere with laminating or soldering operations.	O.2-1

4.1.3.2.2 Interconnector Configurations

Hughes reported that expanded silver-plated copper mesh, which had been rolled after expansion, caused silicon "cratering" (local spalling) in the solar cells at low temperatures. They now use an etched copper grid mesh with wider openings (N.4-31, p 30).

(Between para. 5 and 6 of p. 4-141 insert the following):

TRW has developed a "notched long-life ribbon" design which is claimed to minimize thermal stress "by adjusting the interconnector length to the ratio of coefficients of thermal expansion between the interconnector material and substrate". This is accomplished by attaching one end of the ribbon to the "P-contact directly below the point where the next interconnector is attached to the N-contact". However, "when (interconnector) in-plane stress relief loops are encapsulated in the elastomers used to bond solar cells to a substrate, the deformation of the interconnection is not free anymore. At lower temperatures where the elastomer becomes hard and brittle the captured stress relief becomes useless." (Ref. T.3-36).

4.1.3.2.3 Interconnector Joining Processes and Materials

Table 4-12 Joining Techniques for Solar Cell Interconnections-Ultrasonic Bonding

Source:	Comments	Bib. No.
Ion Physics Corp.	'Soft aluminum' further defined as "1100 Aluminum ribbon, 320 mils wide. Bonding was performed using Unitek/ Weldmatic equipment. Tip Pressure - 7 oz. Time - approx. 1.8 seconds Power setting on Pwr. Supply - 12 watts	I.3-15

4.1.3.3 Solar Cells

Significant progress has been reported in only two areas of solar cell technology in the past 1 1/2 years. The wraparound contact cell technology has been advanced by the completion of two development contracts by each of the two domestic suppliers of solar cells. These contracts called for contact design, evaluation, developing fabrication techniques, building production-type tooling, and manufacturing some 4000 cells total.

The second area of reported progress has been the producing of a gallium-aluminum-arsenic/gallium arsenide cell by the IBM Corp. It is reported to have an efficiency of 18%. These two areas as well as the status of the silicon, cadmium-sulfide, and lithium doped technology are detailed below.

Silicon Cell Status

It has been reasserted that 20 to 22% theoretical efficiencies can be realistically expected from silicon solar cells if all material and fabrication techniques were optimized. Studies to more completely understand the mechanisms involved so that the processes can be optimized continue at a slow pace because of low level of funding. The efficiencies of production run cells continue at 10 to 12%, the same as for the past several years, with special laboratory produced cells at 12 to 14.7.

Pertinent data and the current status of the silicon cell and its variations, as well as CdS and Cd Te cells is given in Table 4.1.13.

Wraparound Contacts

Two separate programs to advance the wraparound contact technology were completed within the past 1 1/2 years. Both Heliotek and Centralab completed contracts from NASA-Lewis and LMSC. Both contracts called for contact design evaluation, developing fabrication techniques, building production-type tooling, and producing a total of 4000 cells. The NASA-Lewis contract was somewhat more of a parametric study and restricted to 2 x 2 cm cells, while the LMSC contract was directed toward the design of a cell to be used on the large Space Station and therefore also concerned

FOLDOUT FRAME

Table 4.1.13 COMPA

	CONVENTIONAL SILICON	WRAPAROUND ELECTRODE	LITHIUM-DOPED	ION-IMPLANTATION
Manufacturing Methods	Boron-doped substrate with phosphorous diffusion. N on P is standard.	Same as conventional cell with additional masking and dielectric gap on back.	P on N junction cell with small quantities of lithium diffused into the cell.	Accelerated ions used to control accurate doping of cell.
Size	Standard size of 2 x 2 cm, 6 to 14 mils thick.	2 x 2 and 2 x 4 cm, 10 to 14 mils thick.	Standard size of 2 x 2 cm, 6 to 14 mils thick.	Standard size of 2 x 2 cm, 6 to 14 mils thick.
Efficiency	10-11% AMO average.	Apparent power increase. Output increased 3% due to increased active area.	11% AMO average.	11% AMO average.
Temperature Performance	Power change of -0.6% of original per ^{o}C.	Power change same as conventional cell.	Unirradiated cell power change same as conventional cell.	Power change same as conventional cell.
Cost	$3 to $6 each in large orders.	$10 to $50 each in small quantities. 5 to 20% more expensive than conventional cells in production.	Approximately 10% more expensive than conventional cells in production.	$6 to $10 each. Production is limited at this time.
Weight	2.3 gm/cm^3 silicon, 0.015 g/cm^2 of solder area 10-mil soldered cell weighs 0.2932 gm each, average	10-mil cell weighs 0.2932 gm.	10-mil cell weighs 0.2932 gm.	10-mil cell weighs 0.2932 gm.
Cost of Cells/ft^2 of Array Module	(200 cells/ft^2, $5/cell, 10 mil) $1000	(200 cells/ft^2, $5.50/cell, 10 mil) $1100	(200 cells/ft^2, $5.50/cell 10 mil) $1100	(200 cells/ft^2, $8 cell, 10 mil) $1600
Watts/ft^2 of Array Module at 0^{o} Angle of Incidence	(61.1 mW average at 25^{o}C AMO 2Ω-cm, 10 mils nominal) 14.2	(62.9 mW average at 25^{o}C AMO 2Ω-cm, 8 mils nominal) 14.6	(10 mils at 25^{o}C AMO 2-Ω-cm) 14.2	(10 mils 25^{o}C AMO 2-Ω-cm 14.2
Radiation Damage	At 1500 nautical miles, 40% degradation in one year.	Same as conventional.	At 1500 nautical miles, 40% degradation in five to ten years. Testing and development continuing.	Same as conventional.
Availability	Available now.	Available now.	Can be obtained in small quantities.	Available now. Production rate capability is low.

ISON OF SOLAR CELLS

LARGE AREA	ALUMINUM CONTACT CELLS	NOTES ON SILICON CELLS	CdS	CdTe
Same as conventional cell.	Sample runs fabricated successfully on several cell sizes.		Vacuum deposited onto plastic-film substrate. Junction formed by chemical dip. Grids cemented with metalized epoxy. Mylar or Kapton plastic encapsulation.	Co-evaporation of Cd and Te onto thin Mo substrate. Copper telluride vacuum flash evaporated to form junction. Evaporated gold grid. Krylon sealing and AR coating, or Al_2O_3 AR coating.
Width: 2 cm to 1.5 in. Length: 2 cm to 6 in. Usually in 2 x 3, 2 x 4, 2 x 5, and 2 x 6 cm sizes	Standard size of 2 x 2 cm, 6 to 14 mils thick.		Standard size of 3 in. x 3 in. area and 2-5 mils thick. Areas up to 1 sq ft possible.	No standard. 2 x 3 cm cells up to 320 cm^2 cells have been made.
Same as conventional cell.	Same as conventional cell.		AMO, Kapton covered 3.3% average in pilot production, 6% maximum.	AM1, Krylon covered, 4.8% average, 6% maximum.
Power change same as conventional cell.	Power change same as conventional cell.	Temperature cycling affects: (1) annealing of radiation damage and recovery of power, and (2) contacts, bonding, and material fatigue	Power change of -0.46% of original per ^oC increase.	Power change of -0.57% of original per ^oC increase.
$6 to $12 each in large orders.	$11 each in small quantities, $3 to $6 in large orders.	Higher average efficiency specs and thinner cells decrease yield, increase cost, and reduce lb/watt.	$25 each in small quantities: Expect to reach $5 each in production.	Unknown.
2 x 4 cm cell is 10 mils longer than two 2 x 2 cm cells. 10-mil cell weighs 0.5901 gm.	10-mil cell weighs 0.2932 gm.		3 in. x 3 in. standard weighs 1.8 gm with plastic encapsulation. A low-weight design is 1.25 gm/cell.	A 3 in. x 3 in. cell with plastic cover would weigh 2 gm.
(100 cells/ft^2, $10/cell, 2 x 4 cm, 10 mil) $1000	(200 cell/ft^2, $5/cell, 10 mil) $1000	Cost savings in larger cell are expected to appear in reduced handling/watt of assembled array.	(14.2 cells/ft^2, $5 cell) $71	Unknown
(122.2 mW average at 25°C AMO 2-Ω-cm 10 mils, 2 x 4 cm) 14.2	61.1 mW average at 25°C AMO 2-Ω-cm, 10 mils nominal) 14.2	B.O.L. Power. Spacing between modules and effects of covers not included.	(0.259 W average at 25°C AMO) 3.68	(0.279 W average for 3 in. x 3 in. cell AM1) 3.96
Same as conventional.	Same as conventional cell. Low Z Al reduces energy deposition in contacts due to nuclear weapons effects.		Low-energy protons cause significant damage. 1-mil Kapton covers drop initial power but limits power degradation to 10% for 10^{14} p/cm^2, 1 to 5 Mev.	Limited data, electron-degradation insignificant. 15% degradation with 7×10^{13} p/cm^2 (2.4 Mev). Krylon covers darken under UV radiation and a polysilane cover has been proposed by the French.
Usual sizes. Available now.	Available now.		Can be obtained at a rate of 50 cells/day now.	U.S. efforts nil at this time. A French government laboratory (Laboratoire E.R.G.) indicates pilot production but effort is mainly developmental.

with a contact design that would be compatible with a flexible substrate integrated with a printed circuit interconnect system. It was restricted to the 2 x 4 cm size cell. Final reports for each program and from each contractor are listed in the bibliography under C.3-13, C.3-17, H.3-19 and H.3-26.

There are two methods of forming wraparound contacts. One is to form a wraparound junction region with a wraparound contact on this region. The alternate method is to make a wraparound contact with an insulating layer between the N contact and the P base area. In the case of the first method the area of the wraparound N contact on the back side must be limited in size and placement so that series resistance does not increase enough to degrade cell efficiency. The second method does not have that limitation and therefore would be desirable. However, because of difficulties in the formation of an adequate insulation layer, all of the three wraparound contact vendors reviewed, Heliotek, Centralab, and Ferranti, have settled on the wraparound junction method, at least for the present.

Although a part of the NASA-Lewis contract has yet to be completed, it appears that the capability of producing the wraparound contact cell by production methods has been demonstrated. Increased cost for the wraparound design as compared to the front contact design has been projected to be between 5 to 20%, depending on quantity. It is hoped that the increased cost would be more than offset by the decreased cost of array panel assembly cost. Figure 4.1.17 shows how the cost of cell varies with cell area and also shows how increased quantity reduces the cost for both conventional and wraparound contacts.

Increased output for the wraparound contact was found to be about 3%, instead of the theoretical 5%. (5% increased active area). The 2% lost is the effect of increased series resistance.

As a result of this work a wraparound contact design that is optimized both mechanically and electrically has been proposed and is shown in Figure 4.1.18 and discussed in the bibliography reference L.4-51.

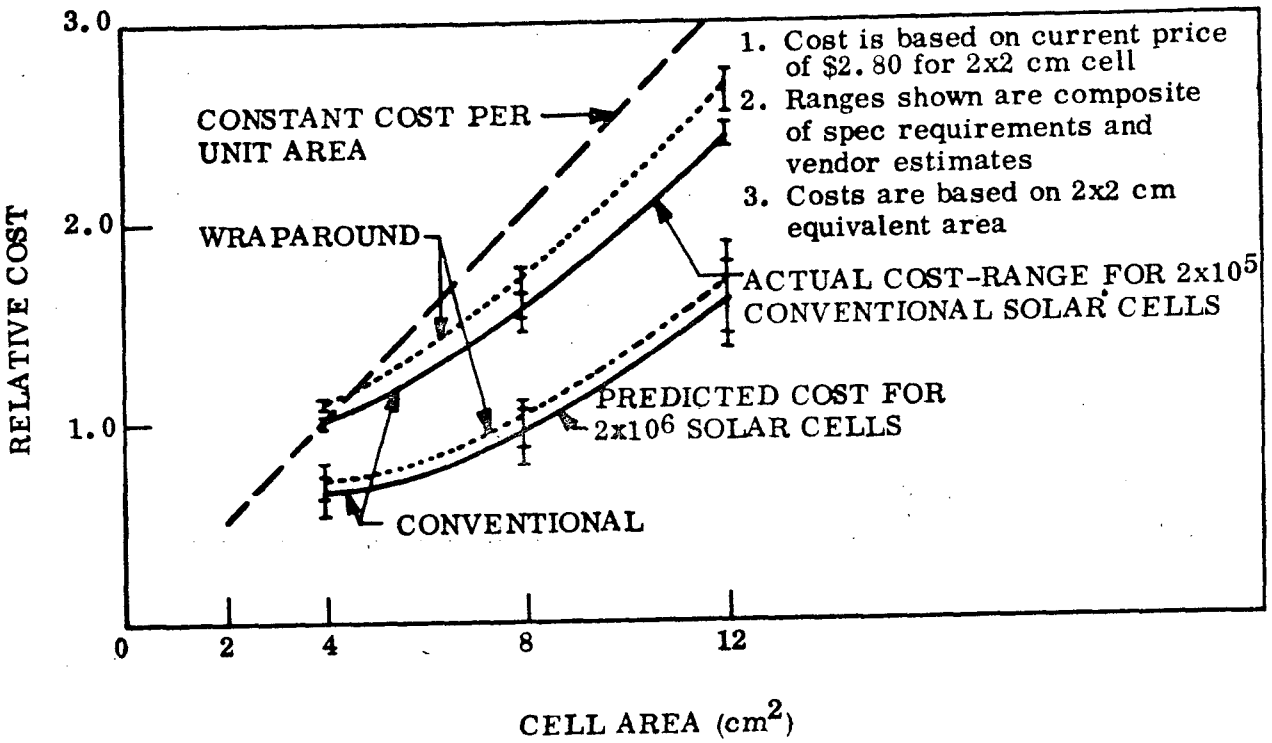


Figure 4.1.17 Cost Vs Area for Solar Cells

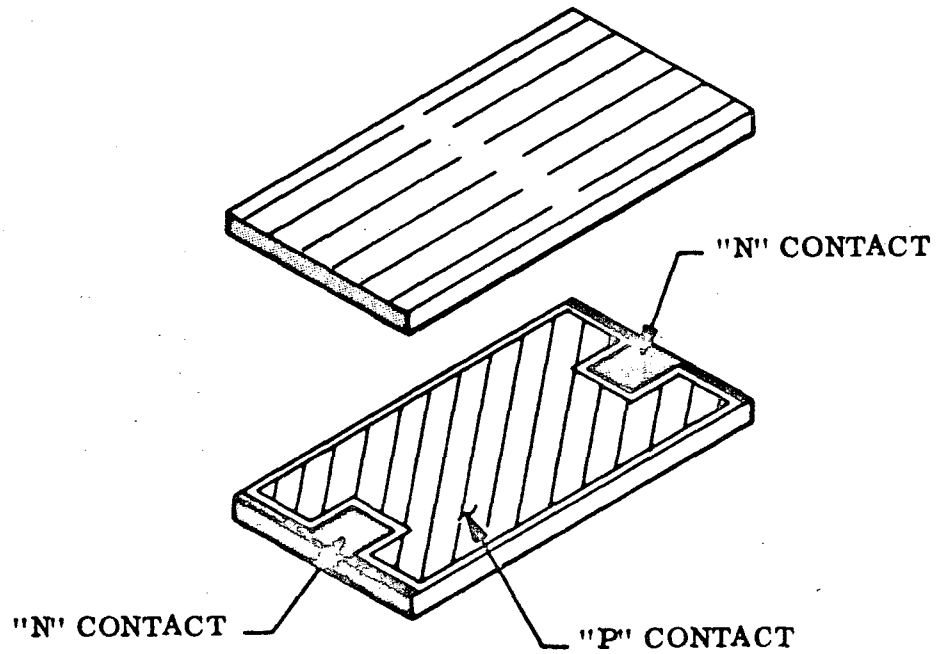


Figure 4.1.18 New Wraparound Contact Configuration

Gallium-aluminum-arsenic on gallium arsenide cell

A recent announcement by the IBM Corp. claims an 18% conversion efficiency for a new type of gallium arsenide cell developed at their Yorktown, N.Y. laboratories. The new cells are not yet optimized, and efficiencies may go higher with refinements in design. Also increased high temperature performance and increased radiation damage resistance is claimed.

As described by IBM, a layer of GaAlAs, heavily doped with zinc, is grown on top of a crystal of n-type GaAs. As the layer grows, zinc diffuses into the GaAs, forming a p-region. Depending on growth conditions, the depth of the zinc diffusion can be controlled to form a p-n junction from 0.5 to 7 microns below the surface. Depth control is simple and the whole process is quite reproducible.

Three reasons stated for the high efficiencies are:

- The process permits reliable formation of a p-n junction within a micron of the surface--a shallow junction is essential because all of the incident solar light is absorbed by GaAs within a couple of microns of the surface.

- Overgrowth of GaAlAs practically eliminates surface states on the GaAs that would normally provide fast recombination sites for electron-hole pairs before they can be separated by the p-n junction to provide electrical power.

- Overgrowth of GaAlAs forms a good electrical contact with GaAs and has very low sheet resistance, reducing losses in the cell and permitting the metal electrodes on the surface to be spaced far apart (i.e., opening more surface to light).

Cadmium Sulfide Cells

As of April 1, 1971, Gould Laboratories (formerly Clevite) has discontinued development and production of the Cu_2 Cd S cell. The only remaining producer of this cell is SAT of France. Presumably, some companies, especially European, will continue to do research in this area.

Lithium Doped Cells

Many reports have been published recently covering work on lithium doped cells. Both the subject of improving fabrication techniques of the cells and the subject of theoretical studies and radiation testing were treated extensively.

Some of the significant results of the reports are:

- Lithium concentrations in the order of 2 to 4 x 10^{14} atoms/cc (lower than had been previously used) seem to produce a higher output cell initially and have a better recovery from radiation damage than cells with a higher concentration of lithium, in the expected radiation environments of low earth and synchronous orbits.

- Power output of the P on N cell have improved with improved techniques of boron diffusion into a phosphorous doped base. N on P cell, the industry standard for many years, has phosphorous diffusion into a boron base.

- Considerable progress has been made in identifying the various mechanisms that are important in the production and annealing of radiation damage in the lithium doped cells. Improved concepts and models have been proposed.

- All cells degrade more from radiation when illuminated and loaded

- Pilot runs of several hundred cells produced cells of efficiencies as good as conventional N on P cells.

- Counterdoping, or the lithium doping of N on P cells, has shown some promise.

However, the industry still does not seem any closer to using lithium doped cells on any space program. Reasons most often cited are uncertainties as to the long term lithium concentration stability in storage and operation, and of transferring laboratory and pilot line techniques to production quantities.

4.1.3.4 Coverglasses

During the current Technology Evaluation reporting period (December 1970), there were two main areas of study that have advanced the solar cell coverglass technology applicable to the Space Station Solar Array. First, in the area of FEP coverglass development, both LMSC and NASA Lewis (Ref. Bib. L.4-34 and N.6-34 respectively) have reported on recent investigations which have produced more data on FEP/solar cell combinations. This is presented in Table 4.1.14, below. Note that the micrometeoroid damage seems little more than a measure of the loss in coverglass transmittance.

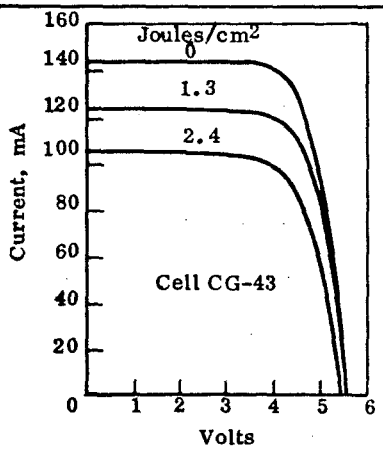
TABLE 4.1.14

FEP THERMAL PROPERTIES AND ENVIRONMENTAL EFFECTS

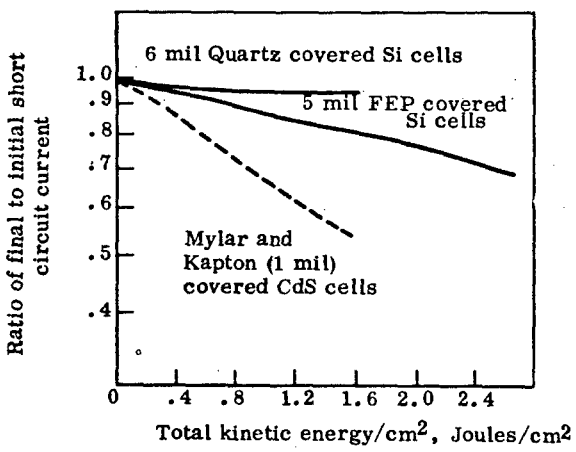
5 Mil FEP over 12 Mil Centralab Cell

THERMAL PROPERTIES	RADIATION EFFECT
α = 0.83 ϵ = 0.88 $\frac{\alpha}{\epsilon}$ = 0.94 ρ = 2.1% η = 1.34	o 1% loss in I_{sc} after 52 equivalent sun hour o 5% loss in I_{sc} after 2.08×10^{17}, 2 KEV protons/cm^2 o Catastrophic failure after 10^{16}, 2 MEV Electrons/cm^2 (very high dose rate may have been the cause).

MICROMETEOROIDS



Typical 1-V characteristic of FEP encapsulated 2x2 cm silicon solar cell before and after exposure to simulated micrometeoroids.



Effect of exposure energy on the ratio of final to initial short circuit current for various solar cells.

The second major area of study concerns the work done by Heliotek and Ion Physics (Ref. Bib. N.3-21 and I.3-16 respectively) on the integral coverglassing of solar cells. Two new types of glasses were investigated--Corning 7070 glass at Ion Physics and Corning 1720 glass at Heliotek--that were found capable of being deposited to any desired thickness without the inherent stress problems of deposited fused silica. The radiation resistance of the two glasses, although not as good as the fused silica, was significantly better than 0211 microsheet. Due to more optimum index of refraction, T_iO_x (Heliotek) and CeO_2 (Ion Physics) were used instead of the tradional S_iO_x solar cell coating.

4.1.3.5 Flexible Flat Conductor Cable Wire Harness

No new flexible array feeder harness applications have been reported during the update period. Therefore Chart Q required no additions or improvements.

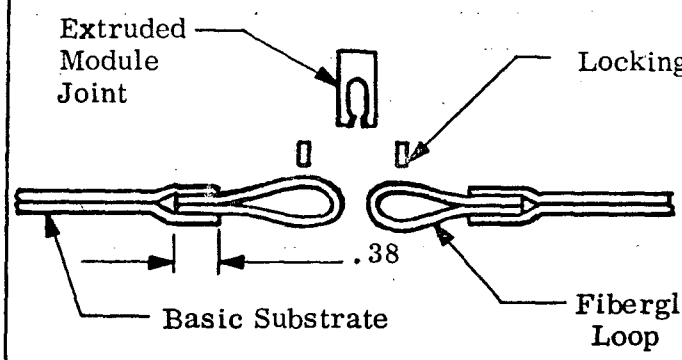
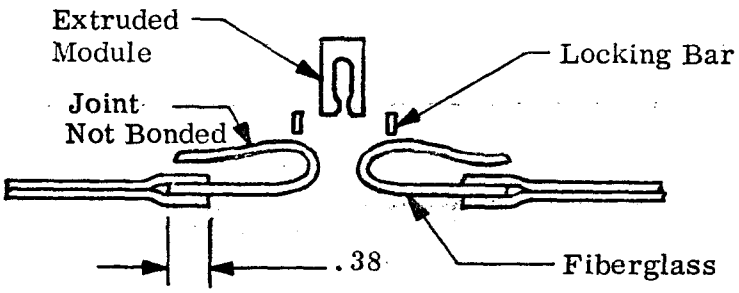
The only work of interest here, performed by Martin Denver under NASA-MSFC contract (mentioned in the original First Topical Report – page 4-194), was completed and the Final Report (see Biblio M.1-11) published in October 1971. It had as its objective the design, development and manufacture of devices for connecting solar panel circuitry to flat conductor cable (F. C. C.). Under this contract effort nine connecting concepts were investigated and one was chosen to design, fabricate, and test. Its thickness of 0.180 inch makes it attractive for solar array usage.

Another interesting concept consisted of folding over the stripped FCC, forming it with a seam and hooking the pieces to be joined together. Its thickness of 0.026 inch makes it extremely attractive. Even though it was not chosen for development because its reliability during thermal cycling is questionable, it could be worthy of further consideration.

Footnote: Report N.10-1, mentioned in the Blue Book is now included in the bibliography since it provides extensive basic information on the whole field of F.C.C. and F.C.C. connectors under development.

4.1.3.6 Substrate Assembly Joining Techniques

Two new joining techniques were developed under the Space Station array contract and are shown schematically below.

Config. No.	Joint	Tensile Strength (Lb/In) -80°F	70°F	170°F
1		44.7	36.7	33.3
2		42.7	33.0	29.7

A photograph of a small sample of configuration number 1 is shown in Figure 4.1.19. Neither joint exhibited a creep rate under 14 lb/in loading at 140°F for 30 days.

Noting that the tensile strengths of the two joints is approximately the same, the major advantage of configuration 2 is that it is much easier to manufacture and assemble than configuration 1. The major disadvantage is its slightly higher susceptibility to tearing.

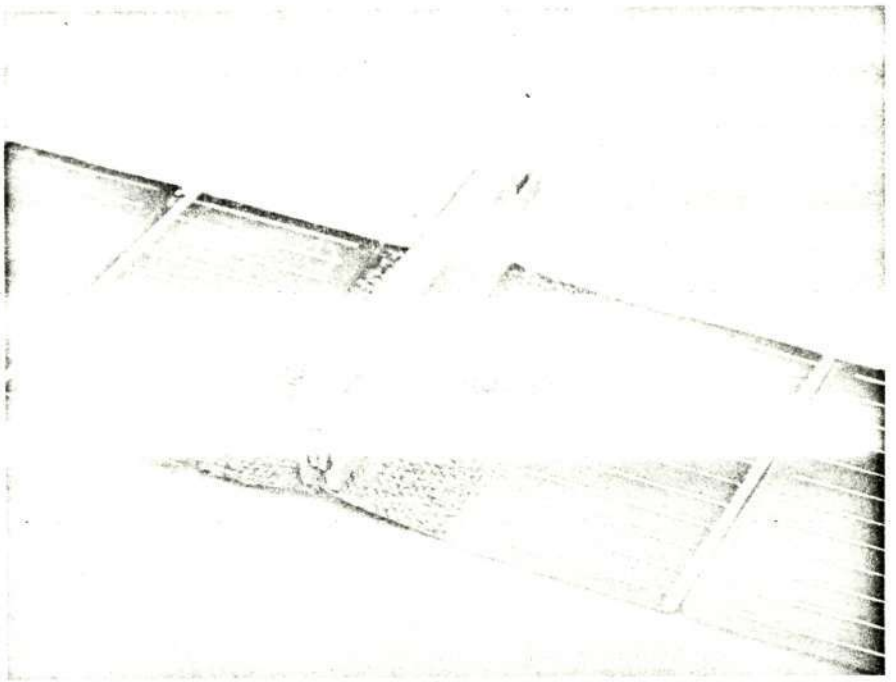


Figure 4.1.19 Completed Space Station Array Module Joint

4.1.3.7 Flexible Substrate Thermal and Optical Properties

Since the last reporting period, thermal properties of the SSSA flexible substrate materials have been obtained and are presented in Table 4.1.15. Front side properties of both Heliotek and Centralab wraparound cells (with and without the filters on 12 mil fused silica covers) were measured. In addition, backside properties for both cells (both bare and covered with substrate materials) along with properties of the other substrate materials were determined.

TABLE 4.1.15
THERMAL PROPERTY MEASUREMENTS ON LMSC 2x4 CM
WRAPAROUND SOLAR CELLS AND SUBSTRATE MATERIALS

Position	Solar Absorptivity		Normal Emissivity	
	Heliotek	Centralab	Heliotek	Centralab
Front (with blue filter on 12 mil fused silica)*	.742	.708	.809	.808
Front (without blue filter on 12 mil fused silica)*	.826	.804	.809	.811
Back	.104	.094	.030	.030
Back (covered with substrate - 1 mil Kapton - 1 mil FEP - 1 mil Kapton	.334	.333	.840	.840

Kapton Fiberglass (1 mil Kapton - 1/2 mil FEP - 5 mil Dodge 368-5 FEP Fiberglass - 1/2 mil FEP - 1 mil Kapton)

α = .697 ϵ = .878

Kapton-FEP-Copper (looking through 1 mil Kapton, 1/2 mil FEP at Olin Brass Company Printed Circuit Copper)

α = .45 ϵ = .75

*Sylgard 182, unprimered adhesive

4.1.3.8 Thermal Cycling

Table 4.1.16 is a summary of solar array temperature cycling test programs to date including results and conclusions. It is an expansion and update of Chart Q in the Blue Book. The data presented has been increased and rigid array testing has been added. The purpose of the addition and expansion is to more adequately survey the field in preparation for a temperature cycling plan to address the serious deficiencies in this testing area that were itemized in the First Topical Report. Even with the updating, it can be seen that in general, the deficiencies are still present, especially in the comparative data area. Blank squares in the chart indicate the data was not stated in the report.

The general conclusion is that the series interconnects and the interconnecting solder joint present the most serious problems. Since some of the soldered joints do survive even the most severe testing, the problem is probably one of quality control. However, considering the number of solder joints and series connections in the larger arrays (4,000,000 on the 10,000 ft^2 Space Station array) the quality control problem could well be insurmountable on a production basis. Therefore more emphasis should and is being placed on other techniques such as welding to replace soldering and wrap-around contacts to eliminate stresses on series interconnects.

FOLDOUT FRAME 1

TEST SAMPLE										
BIBLIO. NO.	TEST YEAR	COMPANY	CELL			SUBSTRATE	INTERCONNECT	VACUUM DESCRIP.	RADIATION DESCRIP.	CONVECTIVE DESCRIPTION
			DESCRIPTION	SERIES	PARA.					
L.H-3	1967	Lockheed	2×2 cm 14 mil soldered	5	5	Kapton "F"	Cu etched printed circuit			Cold box LN_2 blown over samples heating element
S.3-2	1970	Societe Anonyme De Telecommunication	2×2 cm	4	5	Kapton "F"				
M.4-2	1970	MIT Lincoln Labs Dr. Allan Stanley	7 test panels, all 2×2 cm, solder & solderless	4 3 5	4 6 3	6 Honeycomb and 1 Kapton	Copper, molly, kovar, and silver mesh	None		LN_2 dip N_2
R.3-4	1970	Royal Aircraft Establishment	2×2 cm wraparound							
H.3-1 through H.3-4	1970	Heliotek					0.050 in. wide copper, 2, 4, 6 and 8 mil thick			
H.3-12	1970	Societe Anonyme De Telecommunication	2×2 cm	5	3	Al	Copper and conventional design			Heating and cooling in N_2 environment
		Module by Heliotek					Molly and improved design			Heating and cooling in N_2 environment
G.2-5 through G.2-9		General Electric	2×2 cm	(2)4 (1)5	4 5	Kapton	Expanded silver mesh			
H.6-1 through H.6-6		Hughes	2×2 cm	5	2		Expanded copper mesh	3×10^{-6} Torr		
			2×2 cm	10	1		Expanded copper mesh	3×10^{-6} Torr		
H.6-7 through H.6-13 & H.6-25		Hughes	Typical panel segment of flexible rolled up array			Katpon & Fiberglass	Expanded copper foil	1×10^{-7} Torr		
			Same as above except "tighter inspection procedures" used			Same as above	Same as above	1×10^{-7} Torr		
B.3-1 through B.3-4		Boeing					Expanded silver mesh	Vacuum		
R.4-5 through R.4-8		Ryan	2×6 cm	8	1		Al with Ni flash & Ag plate			
			2×6 cm	6	1		Al with Cu flash & Ag plate			
			2×6 cm	4	1		Cu with Ag plate			
			2×6 cm	6	1		Molybdenum, Ag clad			
T.3-40	1969	TRW	2×2 cm 10 mils TiAg contacts with solder coating	6	3	None, Mag., Al., and Pyrex Glass	Copper, molly, & kovar: 1, 2 & 3 mils			

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Table 4.1.16 SOLAR ARRAY TEMPERATURE CYCLING TEST

TEST CONDITIONS					RESULTS		
						FAIL	
NO. OF CYCLES TOTAL	MAX TEMP (°C)	MIN TEMP (°C)	RATE	IN SITU TESTING METHOD	NO FAILURE COMMENTS	INTERCONNECTS	CELLS
1800	+60	-130	30 min cycle	None	No physical degradation		
1248	+56	-170	60 min cycle		No electrical degradation	Minute cracks: 200 to 350 cycles 5 loose tabs after 920 cycles Major failures: 1000 to 1248 cyc.	
217	+60	-196	167°F/hr	None	Kapton did not fail in LN_2 dip	Cracks and lifted tabs	Cracks, minor to major
1200	+60	-160					
500	+80	-130			No failures		
100	+21	-196	5 min/cycle	None		Failures evenly distributed among all thicknesses	
100	+21	-100	5 min/cycle	None		4 & 6 mil had 50% failures, 2 & 8 mil had less than 15% failures	
over 4000	+50	-150	1 hr/cycle	None			
No. of cycles not stated – gentle stress applied during visual exams	+50	-170	1 hr/cycle	None			
34	+140	-130	50 min/cycle			Failures only where forming tool had scored the mesh	
1		-157	2 hr soak				1 cell severely cracked
5	+121	-157	90°/min				New crack in first cell and another cell cracked during third cycle
1	+21	-130	90°/min		No damage		
1	+21	-157	90°/min		No damage		
1	+121	-+21	90°/min		No damage		
		-157	2 hr soak		No damage		
1	+21	-184	90°/min				N strip starting to lift on 1 cell
		-184	2 hr soak				N strip completely lifted on same cell
4	+121	-184	90°/min & 1/2 hr soak at -30°				
100	+93	-184	8 min/cycle				Physical damage at a negative and a positive contact at 25 cycles. Failures at terminal ends of a cell group. No electrical degradation. At 100 cycles, one cell fractured in another group, also at a term. end
2000	+87	-108	55 min at +87 & 30 min to -108		No physical or electrical degradation		
100 – followed by flexural fatigue	+75	-100			No physical damage		
100	+75	-100	54°/min, 1 min soak		No degradation	Stretched and wrinkled	
100	+75	-100	54°/min, 1 min soak			Stretched and wrinkled	
100	+75	-100	54°/min, 1 min soak				
50	+75	-100	54°/min, 1 min soak			Silver oxidized to cause severe discoloration	
300	+100 +60 +100	-175 -162 -130	10°C to 25°C/min			Cracks in interconnects and solder	

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FOLDOUT FRAME 3

UMMARY (Sheet 1 of 2)

RES		CONCLUSIONS
SUBSTRATE	OTHER	
	Slight electrical degradation	
Honeycomb failed in LN_2 dip		Contact failure most serious, amount of solder critical, S/B 0.002 in. maximum. No one metal interconnect seems superior. Kapton is superior to honeycomb in thermal shock.
		Test to evaluate interconnect thickness. Result – inconclusive, thickness probably of second order importance. Solder embrittlement noted.
	Joint failure, 1/3 by several hundred cycles and 2/3 passed 4000 cycles Failure within the solder layer itself generally after more than 1000 cycles	Solder fatigue will be ultimate problem. Thin solder and mild heating important. Molly is best interconnect material. Geometry of interconnect is important. Conventional Pb-Sn-Ag soft solder is superior to several alloys and techniques tested
		Believed to be caused by excess solder
	Small reduction in cell open circuit voltage	Thermal cycling reduces effectiveness of solder joint.
		1 mil molybdenum interconnect and/or pyrex glass substrate best because silicon expansion rate is matched. Analysis shows solder composition is a factor. Presents analysis and graphs.

P

FOLDOUT FRAME 1

TEST SAMPLE										
BIBLIO. NO.	TEST YEAR	COMPANY	CELL DESCRIPTION	CELL SERIES	CELL PARA.	SUBSTRATE	INTERCONNECT	VACUUM DESCRIP.	RADIATION DESCRIP.	CONVECTIVE DESCRIPTION
G.2-1 through G.2-4		General Electric	(3) 2 × 2 cm (1) 2 × 2 cm	5 ea. 5	5 ea. 5		Photo-etched BeCu 0.003 in. thick Expanded silver mesh			
N.2-22	1971	Goddard – Sample module of OAO-B	(47) 1×2 cm			Honeycomb: 6 in. × 11 in. 11 in. × 1 in.	S band loops – soldered. Some bent over, some normal 82 tab connections	In air		
N.2-22	1971	Goddard – entire OAO paddle	4906 1×2 cm			Honeycomb	S band loops, soldered 9,812 tabs	Vacuum		
T.3-34	1970	TRW/NASA/MSFC Moon based array	1170 2×2 cm and 30 2 × 4 cm in random and preferred crystal orientation coverglass 0.006 Dow Corning 0211 microsheet with Dow Corning XR 6-3489 adhesive (Sylard 182). Zone and total soldering	5	2	Epoxy/fiberglass, kapton, and grafhite on Al honeycomb with perforated kapton as insulator. Cell/sub. adhesive was: RTV 3145, RTV 118, PR 1538, and a 50/50 mix of RTV 511 and RTV 577. 8% to 70% bond area and 0.005 and 0.010 in. thick	Kovar 0.001 in. thick	Vacuum		
T.3-37	1971	TRW	2×2 cm nonwrap-around			Kapton-Al laminate, "hardened" construction	Al ultrasonic welding: 3 mills 3 mills 1.5 mills 1.5 mills			
F.3-2	1971	Ferranti	12 interconnected 2×2 cm wraparound, 5 mills thick, 6 mill cms cover-slips using RTV 602 cement			2 mil kapton, no cell/substrate adhesive	1 mill silver plated moly	Air		
	1971	Lockheed	2×4 cm 14 mil	3	3	Kapton, no cell/substrate adhesive	Copper printed circuit with raised series tabs	No vacuum	Quartz tungsten	LN_2 vapor convection
			2 × 4 cm 12 mil	3	3	Kapton, no cell/substrate adhesive and kapton under 1/2 lb/in. tension	Copper printed circuit with raised series tabs	No Vacuum	Quartz tungsten	LN_2 vapor convection
			2 × 4 cm 12 mil	3	3	Kapton, no cell/substrate adhesive and kapton under 1/2 lb/in. tension	Copper printed circuit with raised series tabs	No vacuum	Quartz tungsten	LN_2 vapor convection
			2 × 2 cm wraparound	3	5	Kapton, no cell/substrate adhesive and kapton under 1/2 lb/in. tension	Copper printed circuit	No vacuum	Quartz	LN_2 vapor
N.6-46	1971	NASA-Lewis sample of Hughes roll up array	9 connected 8 mil cells with 6 mil coverglass	3	3	Fiberglass reinforced kapton	Silver mesh	10^{-7} Torr	Auxiliary tantalum wire heater	

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Table 4.1.16 SOLAR ARRAY TEMPERATURE CYCLING TEST S

FOLDOUT FRAME 2

TEST CONDITIONS					RESULTS		
NO. OF CYCLES TOTAL	MAX TEMP (C)	MIN TEMP (C)	RATE	IN SITU TESTING METHOD	NO FAILURE COMMENTS	INTERCONNECTS	CELLS
114, 105, 100 respectively	+93	-130			No damage	Various signs of degradation	
117 & 88	+93	-130				Extensive damage	
	+93	-157					
300	+104	-60		No IV tests – removed for visual inspection of interconnects		22 (25%) cracks, 9 of which were total opens, others were cracks which would have progressed to opens with continued cycling. Failure mode is tab cracks, then opens. 60% of failures occured at bend at solder joint.	
278	+104	-60		No IV tests – removed for visual inspection of interconnects		3.9% open at solder joint (Solder failure) 0.25% cracked tabs.	
2	+120	-173	7°/min, 2 hr soak at extremes		No gross electrical failures measured	Separated solder joints	46 out of 1200 cells showed ling: of the 46, 35 used RT 4 used RTV 118, 7 used PR and no spalling on cells usin RTV 511 and 50% RTV 577 cell/substrate adhesive. 75 spalling occured on cells wi random crystal orientation 2 x 4 cm
650	+100	-180				Fatigue failure of joints	
1070	+100	-100				Weld failure	
2600	+100	-180			No electrical degradation		
1040	+100	-100				Metalurgical deterioration of joints	75% loss in peel strength
500	+80	-196	166°/min down & 255°/min up. Dwell 55 min at -196°		No failure or degradation		
310	+94	-180	36 min cycle	None	Negligible (3%) power degradation		
310	+94	-180	36 min cycle	None	None except as noted		1 cell off and 1 contact sepa at 114 cycles
310	+94	-180	36 min cycle	None	Negligible (2%) power degradation		
310	+94	-180	36 min cycle	None	None except as noted		2 cells off at 200 cycles
2000	+87	-108		Open-circuit voltage and short-circuit current taken in situ by an X-25 filtered short arc xenon lamp	Changes in open-circuit voltage and short-circuit current were within measurement error. No physical changes except as noted		

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FAILURES			CONCLUSIONS
	SUBSTRATE	OTHER	
			Expanded silver mesh low range limit may be between -200° and -250° F.
			Slight bending of tabs does not increase failures – severe bending does. More failures occur in the peripheral tabs. Tab repairs by splicing is not satisfactory. 300 cycles is enough to yield data on this mode, but failures would have continued. "Normal" S tabs failed (25%) as well as "bent" S band tabs, no difference in failure rate unless the abnormal bending was severe. (See below.)
			Vacuum test essential, since with the addition of the vacuum (see above) the failure rate was drastically reduced and the failure mode was changed (assuming the material and workmanship remained the same). Thermal-Vac test important for both quality and acceptance testing.
pal- 3145, 538, 50% the had were	260 out of 1200 cells were loose: 169 of the 260 used PR 1538 for the cell/substrate adhesive. 1 out of 46 spalling failures occured on the graphite substrate. However the graphite substrate needed an Al honeycomb base and perforated Kapton as an insulator		Cell/substrate adhesive modulus of elasticity and coefficient of linear expansion at low temperature should be as low as possible. Adhesive thickness should be minimum. Substrate coefficient of linear expansion should equal silicon. Use perferred crystal orientation cells with adhesive bond surface free from scratches or micro-cracks. Improve quality control of adhesive during its manufacture and application. SiO on zone-soldered cells contribute to failures. Avoid solder wicking on interconnects. Report contains an analytical analysis and extensive physical properties data. RTV 118 demonstrated highest adhesive bond strength reliability. Note: RTV 118 releases acetic acid. The large number of variables made specific conclusions difficult.
		Electrical degradation	Failures occured at 1/10 the number of cycles calculated, probably caused by the lower yield strength of the evaporated aluminum contacts compared to bulk aluminum.
tion			Conventional soldered interconnects can survive these temperatures, but the quality control needed may be impractical, therefore other methods should be developed.
	Fiberglass reinforcing darkened slightly	Strains on the module were visible but did not appear to affect performance	

Section 5
BIBLIOGRAPHY OF SOLAR ARRAY TECHNOLOGY

This bibliography section is an update of Section 6 of the First Topical Report (L.4-47) and should be used in conjunction with that original list. The following list of documents was reviewed and used in preparing this updated Solar Array/Structure portion of the Blue Book.

In this bibliography the documents are listed in alphabetical order by company or by Government Center if no outside contract was involved. Listings are coded with a one letter, two number group, such as A.2.3 which designates the following: A refers to all companies whose name starts with A; 2 refers to the second company in the A listing; 3 refers to the third document in the listing under that company. In each listing, documents are identified by contract number or by conference, symposium, or journal number and by title, month, and year of publication. In addition, a brief abstract of the subject matter treated in the document was added to the bibliography.

To maximize the usefulness to the power system designers, a code was used to indicate whether or not a document had information regarding a specific subject and whether or not a document had information regarding a specific subject and whether or not it was applicable to the Space Station. The code is as follows:

(1) A solid black dot in a column means that the report information concerning that subject is directly applicable to Space Station power system design.

(2) An open dot means the information is useful but not directly applicable.

(3) No dot indicates the document is not considered applicable at this time.

Bibliography coding was designed to be open-ended to allow addition of documents in every area.

TECHNOLOGY EVALUATION – BIBLIOGRAPHY

DOC NO.	ORIGINATOR/DOCUMENT IDENTIFICATION	DATE	BRIEF ABSTRACT	DESIGN SUPPORT FLT SCIENCES	ARRAY BLANKET					ARRAY STRUCTURE							
					SUBSTRATES	CELL COVERS	CELL INTER-CONNECT	SOLAR CELLS	POWER CONDITIONING	STOWAGE METHOD	PROTECTIVE PADDING	DEPLOY./ RETRACTION	END SUPPORT	SUPPORT STRUCTURE	POWER TRANSFER	EXTENDIBLE STRUCTURE
	AEG TELEFUNKEN																
A.1-8	Title: Telesun Solar Cells	No Date	Features of a new 2 x 6 cm cell are described. Two new concepts of contact geometry welded connections; high spectral sensitivity of these newly developed wraparounds are discussed.					○									
	AF-AEROSPACE RESEARCH LABS DEV. CENTER																
A.2-6	Title: Thermal Tests of the Solar Cell Panels for the OV2-5 Satellite	Apr 1967	Results of tests on solar panel array module OV2-5 to determine if temperature limits exist which might necessitate launch vehicle or satellite design changes. No damage to panel is expected for thermal cycles between -50° and 300°F.														
A.2-7	Contract: F04701-69-C-006 Title: Solar Proton Observations at Synchronous Altitude During 1968	Dec 1969	Solar proton absorption at synchronous altitude compiled during 1968.														
A.2-8	Title: Solar Proton Observations at Synchronous Altitude During 1967	Sept 1968	Solar proton absorption at synchronous altitude compiled during 1967.														
A.2-9	SAMSO-TR-70-407 Title: Low-Energy Proton Damage to Silicon Solar Cells	Oct 1970	The effect of low energy (< 2MeV) proton irradiation upon junction properties of silicon solar cells. Measurements explain large power losses of ATS-1 and Intelsat II-4 satellites.														
A.2-10	IEEE Transactions Title: Low Energy Proton Damage to Silicon Solar Cells	Dec 1970	The effect of low energy (< 2MeV) proton irradiation upon junction properties of silicon solar cells. Measurements explain large power losses of ATS-1 and Intelsat II-4 satellites.														
A.2-11	Contract: AF04(695)-1001 Title: Determination of the Critical Failure Mechanism Affecting Reliability of Titan-III Bolts	June 1967	Investigation of stress-corrosion cracking and hydrogen stress cracking on precipitation-hardened stainless steel (17-4 PH) bolt samples. No failures occurred in 1000 hours under conditions of stress-corrosion cracking. Failures occurred 5 times in 5 hours exposure to hydrogen-stress cracking.														
	AF-APL WRIGHT-PATTERSON																
A.3-8	Title: Progress Report on OWS Experiment DO22 "Chemically-Rigidized Structures for Space"	Oct 1968	Tests on the use of expandable structures in space operations show that a double-walled trusscore shell of resin-impregnated glass fiber cloth is most suited for orbital deployment and rigidization. Panels of this with a flexible ablator laminated on one side, impregnated with vinyl acrylic monomer or gelatin resin is rigidized by heating or space vacuum.										●				○

LEGEND:

● – SUBJECT TREATED – APPLICABLE TO SSSA DESIGN AND TRADE STUDIES

○ – SUBJECT TREATED – CONTENT NOT HIGHLY APPLICABLE TO SSSA PROBLEMS

BLANK – MINOR OR ZERO TREATMENT OF SUBJECT MATTER

TECHNOLOGY EVALUATION – BIBLIOGRAPHY

DOC NO.	ORIGINATOR/DOCUMENT IDENTIFICATION	DATE	BRIEF ABSTRACT	DESIGN SUPPORT FLT SCIENCES	ARRAY BLANKET: SUBSTRATES	ARRAY BLANKET: CELL COVERS	ARRAY BLANKET: CELL INTERCONNECT	ARRAY BLANKET: SOLAR CELLS	ARRAY BLANKET: POWER CONDITIONING	ARRAY STRUCTURE: STOWAGE METHOD	ARRAY STRUCTURE: PROTECTIVE PADDING	ARRAY STRUCTURE: DEPLOY./RETRACTION	ARRAY STRUCTURE: END SUPPORT	ARRAY STRUCTURE: SUPPORT STRUCTURE	ARRAY STRUCTURE: POWER TRANSFER	ARRAY STRUCTURE: EXTENDIBLE STRUCTURE
	ALLIED CHEMICAL CORP.															
A.7-1	Modern Plastics Encyclopedia Title: Creep Properties of Plastics	1969-1970	Explanation of creep properties, including definition of creep, creep rupture, creep (apparent) modulus, effect of applied stress level and temperature on creep, and effects of temperature and environment on creep rupture. Included is explanation of use of data in the creep modulus table.		●					○						
	ASTRO RESEARCH CORP.															
A.8-1	Title: Strength and Efficiency of Deployable Booms for Space Applications	1970	Design data derived for three automatically deployable booms: reelable cylindrical shells, coilable lattice structures, and articulated lattice structures. Requirements considered are bending stiffness, strength, compressive strength, and one category of self loading. Results; articulated booms lightest except in self-loading. Coilable are lightest in self-loading. Cylindrical booms occupy least stowage volume.													●
	BELLCOMM															
B.1-2	Title: Solar Cell Flywheel Energy Storage System	Sept 1970	Study on the use of flywheels as an energy storage device rather than batteries for solar power systems during night time operation. Reduction in weight by 20% is realized over other space power systems in the range of 0-250 KW.													
	THE BOEING COMPANY															
B.3-28	Contract: NAS3-11534 Title: High Voltage Solar Array Study	1969	An analysis of problems operating a 15 KW, 2 to 16 KV solar array to power spacecraft ion thrusters from 185 KW to synchronous altitude, and then power transmitting tubes for 5 years. Feasibility and design given.													
B.3-29	Aviation Week and Space Technology Title: Solar Arrays (High Voltage)	June 1971	Proposed study of the ability of high voltage solar cell arrays to withstand the effects of charged particles in the atmosphere. The 15-month study is to be divided into an evaluation, microscopic investigation, and testing phase.						○							

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B.3-30	Supplement to IEEE Transactions on Aerospace Title: A Portable Equatorial Mount for Solar Testing Large Solar Panels	June 1965	Description of a portable electric-motor-driven equatorial mount used in testing large solar panels. Design criteria such as geometrical relationships, structural loads, and gear box details are provided.													
B.3-31	Supplement to IEEE Transactions on Aerospace Title: Infrared Reflecting Solar Cells	June 1965	Method of increasing silicon solar cell efficiency by lowering cell temperature; accomplished by making the cell a reflector of the infrared portion of the solar spectrum. Spectral transmittance, reflectance, and absorption of silicon wafers and N/P and P/N solar cells are presented. Method presented using N/P cell had 11% less absorptance than the standard N/P cell.					○								
B.3-32	Title: Experimental in situ Investigation of the Effects of Protons, Ultraviolet Radiation, and Temperature on Thermophysical Properties of Solar Cell Filters and Other Spacecraft Materials	Feb 1971	An investigation to determine in situ effects of ultraviolet radiation and solar wind protons for materials considered for the 1973 Venus-Mercury flyby. In situ thermophysical property measurements were made on transmissive solar cell filters, opaque solar cell filter stacks, adhesives, 7940 fused silica, kapton film. Sun rate, solar wind rate, and sample temp all increased with time (2400 hours).													
B.3-34	AIAA-6th Thermophysics Conference Title: Space Radiation Effects of a Simulated Venus-Mercury Fly-by on Solar Absorptance and Transmittance Properties of Solar Cells, Cover Glasses, and Adhesives	Apr 1971	Determination (experimental) in situ of the effects of temperature, UV, and solar wind protons on materials (solar cell filters, adhesives fused silica and Kapton film). 2400 hours of continuous radiation – facility testing - exposure levels of 12000 ESH and 10^{16} protons/cm^2, and temperature-active range of 10°C to 140°C.													
B.3-35	Contract: NASW-1859 Title: Investigation into the mechanism of Degradation of Solar Cells with Silver Titanium Contacts	July 1970	Degradation when cells are stored in humid atmospheres determined by electro-chemical test and physical measurements including optical and electron micrographs, X-ray diffraction, electron microprobe mass and internal reflection spectroscope. Degradation behavior varied from cell to cell-all degraded on critical sun facing side of the cell.					○								

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B.3-36	Title: High Voltage Solar Array Operation in the Ionosphere	June 1970	Study of problems associated with the design of a 15 kW array to provide from 2000 to 16000 volts for an ion-thrusted spacecraft that spirals from 100 nm to synchronous altitude in three months. Loss of power by current leakage through plasma studied. Experimental evaluation of uninsulated and insulated modules.			○			○							
B.3-37	7th Internation Power Sources Symposium Title: Solar Array for 16000 Volts	Sept 1970	Same as B.3-36. Analytical approach to ion thruster effects; insulation breakdown is presented. Dielectric testing and ion Bombardment of cell covers are described.						○							
	BROWN UNIVERSITY															
B.4-2	Nasa Grant NGR 40-002-093 Title: Methods of Improving the Efficiency of Photovoltaic Cells	Aug 1970	Analysis predicts efficiency as high as 20%. Two reasons why cells do not yield Theoretical: light produced current falls short of theory value, and junction characteristics are not as good as they should be. Experimental procedures and results are presented.					●								
	BELL TELEPHONE															
B.5-1	Contract: NAS5-9635 Title: Applications Technology Satellite 1 (ATS-1) Particle Data Reduction and Analysis	Dec 1969	A description of the procedures and results of the electron and proton calibrations of two identical satellite experiments is reported. The experiments each consisted of a six-element solid-state detector telescope and electronics, designed to investigate the particle flux and population in the earth magnetosphere.													
	BATTELLE REIC															
B.6-2	Contract: AF33(615)-1124 Title: Space Radiation Damage to Electronic Components and Materials	Jan 1966	Extent of damage is a function of total environment including electrical biases, temperature, (ambient atmosphere) and other factors beside the radiation. Data contained herein assists in making only "ball park" predictions. Effects of three types of radiation-electron, proton and (Bremsstrahlung) which produce ionization in and around components and materials are presented.											●		

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	CENTRA LAB															
C.3-9	(Globe-Union/Hoffman) ASME Publication Title: How Mechanical Requirements Affect Silicon Solar-Cell Costs	June 1970	Paper describing typical cell fabrication. Included are mechanical tests with typical allowable mechanical tolerances. Also included are usual environmental testing techniques for solar cells and possible cost reductions by reasonable relaxation of some of the cell mechanical requirements.					○								
C.3-10	Contract: 952546 (JPL) Title: Research, Development, and Fabrication of Lithium Solar Cells Third Quarterly Report	Apr 1970	Description of work leading to improved Lithium cells. Most improvement comes from crucible grown silicon, reduced boron diffusion cycles, and use of lower temp. Lithium cycles (below 400°C) with longer (up to 8 hours) diffusion times. Better understanding of differences between oxygen rich CCG) and three forms of oxygen (lean) silicon. Possible to obtain medium yields for AMO max. power output over 30 mw for cg, and over 29 mw Lopex Si.													
C.3-12	Contract: 952546 (JPL) Title: Research, Development, and Fabrication of Lithium Solar Cells Final Report, Part 1	Nov 1970	Improvement of Lithium cells using better boron diffusion methods. It is possible to obtain near equivalent AMO I-V values for both oxygen rich and oxygen lean silicon. Cell shipments are summarized, and compared to earlier shipments. Recommendations are given for future work.													
C.3-13 a – e	Contract No. NAS3-15345 Title: Design and Fabrication of Wrap-around Contact Silicon Solar Cells Reports #1, 2, 3, 4, 5	July Aug Sept Oct Nov 1971	Five part report giving the progress in the development of wraparound contact cells. Objectives to be met are: (1) cells with required contract configuration and optimum mechanical and electrical characteristics. (2) techniques which will produce cells in large quantities. (3) delivery of 1000 cells with a minimum efficiency of 10.5% measured at AMO and 25°C presents problems, progress, and planned work.					●								
C.3-14	Contract: (JPL) 952868 Title: Optimized Silicon Solar Cells for Space Exploration Power Systems Final Report	Nov 1971	Description of a program aimed at designing and fabricating silicone solar cells for mission extending from 0.1 to 15 astronomical units. Theoretical analysis with empirical measurements used to design cells for 5 planetary missions. Requirements of the cell for each type of mission given. Suggestions for future design work presented. Fabrication, measurements, and theoretical study are included.													

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	CENTRA LAB															
C.3-15	Title: Increased Output from Silicon Solar Cells		Description of high output (18 mW/cm^2) cells. Discussion of their impact on state-of-the-art for practical applications. Experimental approaches to improvement of cells such as use of back surface finish, reduction of contact resistance, etc., are discussed.					○								
C.3-16	Contract JPL 952546 Title: Research Development and Fabrication of Lithium Solar Cells Quarterly Report	Jan 1971	Studies, resulting in a better understanding and control of lithium cells by lithium concentration at both the back surface and near the PN junction, are reported. Different sequences of fabrication steps and analyses of 300 cells are presented.													
	CLEVITE CORP															
C.5-8	Contract: F33615-68-C-1182, Project: 7885 Title: Thin Film Solar Cell Fabrication Parameter Study	June 1970	Brief description of the processes currently used and alternatives for the manufacture of thin film CdS solar cells. Material costs and productivity of each existing manufacturing process are listed. Procedures include application of the silver pyre ML layer, interlayer-zinc plating, evaporation and deposition of the CdS layer, barrier formation and application of grid and plastic cover.													
C.5-9	Advanced Energy Conversion Pub. Title: The History, Design, Fabrication, and Performance of CdS Thin Film Solar Cells	June 1966	History presented which traces development of CdS cell from 1955. Various possible constructions included with advantages and disadvantages of each. Steps in fabricating the present design are given with important parameters. Operating characteristics presented of the best present state-of-the-art cells along with possibilities for future improvements.													
C.5-10	Contract: F33615-68-C-1182 Project: 7885 Title: Improvements in CdS Thin Film Solar Cells	Mar 1970	Report of two areas of CdS cell development. First, flight panel construction for satellite and balloon testing of CdS cells. Second, effort to improve stability and efficiency of CdS cells. Effort direct to (1) measurement of contact resistance on current collector grid adhesive (2) optimization of cell for low light level (3) optimization of Cu_2S barrier information process (4) investigation of copper modules found on CdS cells degraded in the open circuit voltage mode													

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C.5-11	Contract: F33615-69-C-1732 Project: 7885 Title: Research on the Operating and Failure Mechanism in CdS Solar Cells	No Date	Research into the operating and failure mechanisms of Cu_2S: CdS thin film cells found that short circuit current was sensitive to uniformity of Zn plating. Phase changes resulted when initially formed chalcocite is exposed to air. Djurlet appears to be the phase normally present. Phase transition near 100°C is reversible, as are effects of reduced surface leads and factors which affect threshold voltage for electrolytic deposition of Cu from Cu_2S.													
	COMSAT															
C.6-7	International Solar Energy Society Conference Title: Solar Cell Research at COMSAT	1970	Survey of cell research at COMSAT. Results include data from studies of low energy proton irradiations on partially shielded silicon cells, 1 MeV electron irradiations on silicon cells, and proton irradiations and thermal cycling of cadmium sulfide cells.					○								
C.6-8	Title: Communications Satellite Power Conditioning Systems	Apr 1970	Review of power conditioning systems for the four Intelsat satellites. Silicon solar cells are the prime power source while Ni-Cd batteries are used during eclipse operation. Each system for each of the satellites is discussed, elaborating on advantages and disadvantages. Comparison charts and suggestions for future systems are presented.						○							
C.6-9	IEEE Transactions on Electron Devices Title: Radiation Damage in Silicon Solar Cells from Low Energy Protons	July 1971	Report on low energy proton damage (150-270 KeV) on solar arrays. Damage can occur in uncovered portion of the cell unprotected by the cover slip. Damage is dependent on exposed area and can be reduced by putting an adhesive on uncovered areas or covering all the open area with a close fitting coverslip.													
C.6-10	AIAA Paper No. 71843 Title: System Engineering Tradeoffs for Advanced Communications Satellites	July 1971	From the pool of spacecraft technology there are several items worthy of development for commercial communication satellite use. These are body stabilization, ion engines for north-south station keeping, light-weight, deployable, sun oriented solar arrays, and rechargeable H_2-O_2 fuel cells. Possible spacecraft performance and cost evaluated for a global network model.											●		

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C.6-11	IEEE Transactions on Aerospace and Electronic Systems Title: Summary of European Solar Cell Activities	July 1971	Review of activities in the solar cell field by European manufacturers and agencies which include efforts in research, development, and production of solar cells, covers, and solar cell arrays. Qualification and use of European cells and covers on Intelsat IV programs are presented.					○								
C.6-12	5th IECEC – Las Vegas Title: Summary of European Solar Cell Activities	Sept 1970	European manufacturers and agencies are identified. Review of research development, and production of solar cells, covers, and arrays. Qualification and use on Intelsat IV program presented.					○								
	CHEMPLEX CO.															
C.7-1	Modern Plastics Encyclopedia Title: Film, Sheeting, and Shapes	1969 1970	Report on various films examining characteristics, production, and uses. The various films are: polyethylene film and sheeting, vinyl film and sheeting, oriented polyesterene film and sheet, polypropylene film, all-acrylic films, polyester films, ABS sheet, nylon films, cellulosics film and sheet, fluoroplastics film and sheet, thermoplastic polyurethane film and sheet, PVF film, extruded composite film, styrone foam sheet, polymide film.		○											
	UNIVERSITY OF CINCINNATI															
C.8-1	Department of Aerospace Engineering Title: Stability of Motion of Satellites with Flexible Appendages 3rd Semiannual Progress Report	Oct 1970 Mar 1971	Theoretical study of the stability of motion of a satellite consisting of a main rigid body and three pairs of flexible booms coinciding with the principal axis of the body in undeformed state. The stability is investigated by the Liapunov second method. Numerical results of a computer program are displayed in the form of stability diagrams.	○												
	CARNEGIE-MELLON UNIV.															
C.9-1	Solid State Electronics Article, Vol. 13, p. 1289 Title: Heterojunction Solar Cell Calculations	Feb 1970	Efficiencies computed for feasible semiconductor heterojunction cells of Zn Se-Ga As, Ga P-Si, Zn Se-Ge and Ga As-Ge. Loss in efficiency due to reflection, incomplete collection and internal series resistance. Optimum anti-reflection films are also calculated.											●		

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	UNIVERSITY OF DELAWARE															
D.4-2	JPL Contract 952666 Title: Research Study of the Photovoltaic Effect in Cadmium Sulphide Final Report	Oct 1970	Report on research effort to improve the quality of CdS cells covering four areas. General theory related to heterojunctions with results on optimized doping and grading, production of materials with reproducible behavior, experimental and theoretical investigation of the behavior in the immediate neighborhood (~ 100Å) of CdS: Cu_xS junction, analysis of changes in parameters caused by radiation damage and changes in ambient atmosphere.													
	ELECTRO-OPTICAL															
E.1-5 and E.1-6	Contract: NAS1-9495 Title: Development of Lightweight Aluminum Hollow-Core Solar Cell Technology, Quarterly Report	Jan 1971	Report describing effort to prepare a 500 gallon batch of new mixed ether aluminum plating solution. Methods of overcoming impurity problems in aluminum chloride are presented. Deposits were produced with strength exceeding 28,000 psi. Techniques for analyzing solutions are presented.													
E.1-7	Contract: NAS7-428 Title: Development of Lightweight Solar Panels Quarterly Report	Nov 1967	Report on Phase II of development of lightweight solar panel to improve Phase I panel (42 lb/kw) to 27 lb/kw. To be achieved by utilizing an electro-formed aluminum hollow-core substrate and a beryllium frame.													
E.1-8	Contract: NAS7-428 Title: Development of Lightweight Solar Panels Quarterly Report	May 1968	Development of solar panels from Nov. 1967 to Apr. 1968. Goal was to fabricate two 5 ft by 5 ft solar panels using biconvex electroformed aluminum hollowcore substrates with beryllium support frames (27 lb/kw). Includes thermal, dynamic, and weight analysis, results of tests to determine strength and modulus of elasticity of electroformed aluminum, and fabrication of frame hardware.													
E.1-9	Contract: NAS2-3613 Title: Silicon Solar Cells for Near-Sun Missions	No Date	Work done on near-sun solar cells to operate at .2Aμ. Optimization at short-circuit current at 1-sun intensity, open circuit voltage at 25-sun intensity. Cells were produced and tested up to a 10-sun intensity. Includes cell fabrication procedures.													
	ESRO															
E.2-10	Title: Development of an Advanced Control Circuit for Satellite Power Systems First Progress Report	Mar 1970	Investigation for the improved electronic control of power sources in a satellite. Method has three advantages: optimum loading of the solar array, load sharing between power regulators to control high power levels, and stability of operation.												○	

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	ESRO-TN-80															
E.2-11	Title: Advanced Solar Cell Array Concepts	Aug 1969	Determination of potential improvements in solar array design. If 40 w/kg is to be realized, then solar cell performance must be improved and new designs for the structure of panels must be made. Discussion of some of the various solar arrays.													
	ESRTC															
E.3-3	Title: Calibration of Solar Cells	Nov 1969	Reasons given for interest in standard solar cells accurately calibrated with respect to AMO short-circuit current. Calibration performed on a satellite, balloon, or on the determination of absolute spectral response of the cells, or terrestrial sunlight at different solar elevations. Principal advantages, and disadvantages are given.					○								
	EXOTECH															
E.4-3	Title: Space Environmental Effects on Solar Cell Power Systems	Jan 1968	Comprehensive discussion on solar cells, including theory of operation, instrumentation techniques to measure solar cell parameters, radiation damage to cells, coverslides, adhesives, and optical filters, radiation shielding, radiation effects on power conversion and regulation equipment, effect of materials, flight test data, and design methods for power systems.													
E.4-4	Contract: NAS12-2237 Title: Second Interim Scientific Report Design Criteria Monograph for Space Vehicle Solar Cell Arrays	June 1970	Report which covers work done during a meeting of the "ad hoc" Advisory Panel to review, critique, and add development to FRC SVDCO-approved content development boards. Also, work was done in revising and expanding the CDB's to reflect the recommendations of the advisory panel. Emphasis directed to coverage of energy conversion mechanism and efficiency methods for optimization (electrical), alternative designs, environmental factors.													
	FAIRCHILD HILLER															
F.1-12	Contract: NAS5-3988 Title: Positive Deployable Solar Array Development Program	July – Sept 1964	This is a report which presents the results of a study to select an optimum design for a compact storable solar array system for use with spin-stabilized satellites. The most critical requirement imposed on the design was found to be 1"g" condition and the limited depth of the package.													
F.1-13 -14 -15	Contract: NAS1-10155 Title: The Study of Dynamic Interaction of Solar Arrays with Space Stations 3 Interim Reports	Feb 1971 to Mar 1972	This study provides the methodology and analyses for design of large area solar arrays for use with space stations. SASS DYNE II & III is a system of digital computer programs for implementation on the CDC 6000 series computer. Zero and artificial gravity simulation and complete miscellaneous solution of system dynamics equations are included.	●												

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	FERRANTI LIMITED															
F.3-1	Title: Proposal to the MESH Consortium for Solar Generators for ESRO Satellites TD1 & TD2	May 1967	This is a proposal for design and manufacture of solar generators. Design data, design procedures, manufacturing methods, and general proposals leading to the construction of a complete array are given.													
F.3-2	Title: Satellite Power Sources – Silicon Solar Cells	Dec 1971	Description of solar cell. Production of both conventional, wraparound, and covered cells. Comparison of competitive cell performance is also included. I-V curves for all Ferranti cells are presented.													
	FRANKLIN INSTITUTE RESEARCH LABS															
F.4-1	Contract: F19(628)-67-C0273 Title: Design and Develop Solar Cells Final Report	Apr Mar 1970	This is a report which describes work done with the photovoltaic effect of organic substances such as chlorophyll solutions and a donor or acceptor. Voltages measured were a few millivolts, using solid-lamellar systems of chlorophyll and organic substrates; the voltages were generally found to be higher.					○								
	FABRIC RESEARCH LABORATORIES, INC.															
F.5-1	Title: Yarn and Tape Tensile Properties in Vacuum	May 1970	Report on tensile properties of nylon, dacron, nomex, PBI, X-101, PRD-14, and fiber glass yarn determined in vacuum (10^{-6} torr) at 70°F after 7-10 day and 45 day vacuum exposures. No effect of vacuum was seen except in X-101 and nylon, where the tensile modulus varied by 10-25%. Also the rupture elongation of nomex, and modulus and rupture elongation of dacron and PRD-14 varied by 10-25%. Tensile strength of fiberglass increased by 30%.													
F.5-2	Title: Mechanical Properties and Flammability Characteristics of Fibrous Materials	June 1970	Report on exploratory research, development, and evaluation of high strength, thermally durable, flexible, fibrous structural materials for aerospace systems. Also new BBB fiber was tested, and improvement in attachment of fiber tape to other structures was shown.													
	FARADAY LABS															
F.7-1	NBS Space Simulation Conference Title: Space Measurements of the Contamination of Surfaces by OGO-6 outgassing and their cleaning by Sputtering and Desorption	Sept 1970	Primary source of outgassing on the satellite was solar panels baking out in the sun. Maximum amount of contamination absorbed by Al and Au surfaces (5 months) was 9.6 $\mu g/cm^2$ for Al and 5.2 $\mu g/cm^2$ for Au surfaces.													

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	GENERAL ELECTRIC															
G.1-2	Contract: DA-49-146-XZ-570 Title: The Trapped Radiation Handbook	Dec 1971	Contains abbreviated but complete derivations of equations and development of concepts in a wide range of subject matter pertinent to the radiation belts. Contains brief descriptions of the magnetosphere and phenomena affecting trapped particles, mathematical models of fields, and effects of trapped radiation and environment on spacecraft system.													
	GENERAL ELECTRIC-VALLEY FORGE															
G.2-20	Thermal Control Working Group Meeting Title: Thermal Design of the Gravity Gradient Test Satellite	Aug 1967	Results from the gravity gradient test satellite show that after one year it is still in its stabilized attitude position. Thermal control has shown itself to be successful. Includes pictures of satellite.													
G.2-21	AIAA Paper #72-569 Title: Results from Tests of a Large Lightweight Solar Array Unit	Apr 1972	250 sq. ft, 79.3 pound rollup array unit tested in environments and for performance before and after. The dominant test problems for this type of equipment is the accommodation of gravity forces without interference with test results. Survey ability and design performance beyond such tests are discussed.		●		○	○		●			○	●		●
	GULF GENERAL ATOMIC															
G.5-1	JPL Contract 952387 Title: Radiation Effects in Silicon Solar Cells Quarterly Progress Report	July 1970	Report on the nature of the defects which cause the degradation in output of silicon devices irradiated by space radiation. Then it will be possible to make radiation-hardened devices, to predict the effects of radiation and annealing on solar cells, and to use computer programs to predict radiation effects.													
	GENERAL PRECISION															
G.6-1	Title: Research and Development of Solar Cell Contacts First Quarterly Report	Apr 1968	A program to optimize Solar Cell contacts and improve interconnections between solar cells which can survive the space environments, dependent upon the achievement of an ohmic, low resistance, adherent stable contact to cell. Adherence achieved of thin-film deposited material was Librascopes proprietary cold substrate deposition process.				○	○								

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	GULF RADIATION TECHNOLOGY															
G.7-1	Contract 952387 Title: Study of Radiation Effects in Silicon Solar Cells	Jan 1971	Research on the radiation effects in lithium-diffused bulk silicon to determine the nature of the defects which cause the degradation in output. Also, a computer code including theory and operation is presented which can be used to predict steady-state I-V characteristics of solar cells with arbitrary doping profiles, spectral light intensity, and non-uniform radiation damage, etc.													
	HAWKER SIDDELEY DYNAMICS LIMITED															
H.2-2	Journal of the British Interplanetary Society Title: X4 Satellite Current Design Features and Applications	1971	Discussion on work being done by the British on their X4 satellite. Satellite has two complementary design aims. They are: two meteorological experiments, and the proving of an attitude control system using propane gas with high pointing accuracy. Includes discussion of power subsystem, attitude control, and configuration and structure.													
	HELIOTEK															
H.3-14	Contract 952560 Title: Development of an Integrated Lightweight Flexible Silicon Solar Cell Array Quarterly Report 2	Oct 1969 – Jan 1970	Presents progress in the development of an integrated lightweight flexible silicon solar cell array. The report includes: cost effectiveness comparison of solar cell coverglasses, detailed analysis of solar cell interconnect thermal stress, analysis of the interconnector and array substrate materials.			○	○									
H.3-15	JPL Contract 952547 Title: Development of Lithium-Diffused, Radiation Resistant Solar Cells. Final Report, Part II	Nov 1971	Description of work performed to investigate the effect of various process parameters on the performance of lithium-doped P/N cells. Effort was concentrated in the starting material, the Boron diffusion, the lithium diffusion, and the contact system.													
H.3-16	ASME Publication Title: Silicon Solar Cell Array Interconnector Design	June 1970	Report on problems encountered in the design of solar cell interconnectors. Problems arise from missions which are 10-12 years, when weight of the arrays is reduced by a factor of three to five, when vibrational loads are increased significantly, when arrays become flexible, when there are thermal extremes, or when thermal cycles are rapid over a wide temperature range.				●									

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H.3-17	Contract 952547 Title: Development of Lithium-Diffused, Radiation Resistant Solar Cells Final Report Part I	July 1970	TiAg, TiPdAy, and Al contacts were tested for strength and humidity resistance. All were tested using soldered bonds and ultrasonically welded bands. BBr_3 was investigated as an alternative boron diffusion source. Evaporation of lithium was investigated also. Eight hour lithium diffusions at 325°C were investigated.													
H.3-18	Contract: JPL 952547 Title: Development of Lithium-Diffused, Radiation Resistant Solar Cells Third Quarterly Report	Apr 1971	Two diffusion processes explored as to output, yield, and degree of stress produced during diffusion. Process were BeI_3 (no O_2) and BeI_3 (with O_2).													
H.3-19 -a, -b, -c, -e, -f, -g and -h	Contract NAS3-15344 Title: Design and Fabrication of Wraparound Contact Silicon Solar Cells Monthly Reports 1, 2, 3, 4, 5, 6, 7, 8	Sept, Oct, Nov, 1971	Reports on the progress in the development of wraparound contact cells.					●								
H.3-20	JPL Contract 953171 Title: Development and Pilot Link Production of Lithium-Doped Solar Cells First Quarterly Report	Dec 1971	Description of work being done on the production of lithium-doped P/N cells. Purpose of work is to demonstrate that the cells can be manufactured in an economical fashion. BeI_3 with and without O_2 were both tried and lithium evaporation studies were conducted.													
H.3-21	Contract NASS-21510 Title: Development of Integral Covers on Solar Cells Final Report	July 1971	Presentation of development techniques and evaluation of electron beams for the evaporation of a dielectric shielding material onto the N/P solar cells. Program evaluates cleaning processes, coating materials, and evaporation processes. TiOx is shown to be the most desirable cell anti-reflective coating. Parameters are given which provide an optimized cover comparable to conventional platelet systems in performance and environmental stability.			●										
H.3-22	Contract JPL 952547 Title: Development of Lithium-Diffused, Radiation Resistant Solar Cells Final Report, Part II	Nov 1971	Description of work done in four areas of the effect of process parameters on the performance of lithium-doped P/N solar cells. Four areas of concentration were the starting material (comparison of high and low oxygen content silicon), boron diffusion (to produce high efficiency cells with minimal stress), lithium diffusion, and contact systems (investigation of sintering of TiAg contacts and evaluation of contact integrity.											◐		

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	HELIOTEK															
H.3-23	Contract NAS2-5519 Title: Research and Development of Silicon Solar Cells for Low Solar Intensity and Low Temperature Applications	Feb 1970	Obtained a solar cell design optimized for 5.0 mW/cm^2, -135°C operation – Jupiter spacecraft mission. Experiments conducted to analyze and optimize important variables, Phase II. 500 cells to be fabricated. Broken fuel effect, cell thickness, cell active interface finish, and auto reflection coating investigated and reported.													
H.3-24	Contract: F33(615)-70-C-1619 Title: Manufacturing Methods for Protecting Silicon Solar Cells with Integral Coverslips	Sept 1970	Study of relative merits of SiO, TiO_2 and CeO_2 as antireflection coatings on Si solar cells. Increased electrical performance of about 3 to 5% was obtained with the TiO_2 coatings compared to the SiO coated cells after a coverglass was applied.			○										
	HUGHES AIRCRAFT															
H.6-23	Interm. Elec. Circuit Packaging Symp. Title: Application of Polymide Film in Chip Packaging and Interconnection	1969	Report on the use of polyimides in microelectronics giving the advantages, disadvantages, inconveniences, and uncertainties. Polyimide film is transparent, infusible, nonflammable, has outstanding electrical properties, and is an excellent resistance to radiation, chemicals, water, and abrasion.													
H.6-24 6-25	JPL Contract 952351 Title: Solar Cell Flight Experiment First and Second Quarterly Progress Report	Dec 1968 Mar 1969	Report on solar cell radiation flight experiment to determine effects of solar radiation at synchronous orbit. Experiment consists of 80 cells on two panels. Data will be used for design of extended spacecraft missions in synchronous orbit.													
H.6-26	Contract NAS3-11535 Title: High Voltage Solar Array Study	May 1970	Study to determine the feasibility of high voltage (2 to 10 kv) arrays capable of 15 kw. Problems raised include plasma power losses, dielectric stresses and questions relating to high voltage design, fabrication, and testing.						○							
H.6-28	Contract NASA CR-1688 Title: Parametric Analysis of Microwave and Laser Systems for Communications and Tracking Prime Power Systems Vol. III-Reference Data for Advanced Space Commun. and Tracking Systems	Feb 1971	Survey of various power systems which can be used onboard spacecraft of each, plus a brief explanation of the principles of operation. Power systems covered include solar voltage systems, solar thermoelectric, thermonic, and dynamic systems, and various nuclear power systems.													

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H.6-29	Report AFAPL-TR-68-76 Title: OLSCA Orientation Linkage for a Solar Cell Array	July 1968	Report on a program to develop the technology to actively orient 1/2 to 20-kw solar cell arrays on actively and passively stabilized earth-oriented satellites which have mission life times of 3-5 years. 5 kw array design developed. Specification of a two degree-of-freedom gearless mechanism using sun-sensing, direct shaft torquing, and power transfer by slipring/brush assemblies. Dry lubricating used throughout.	○												
H.6-31	Contract: F04701-68-C-0145 Title: Radiation Effects on Space Power Subsystems Vol II – Part I	Jan 1969	Data and guidelines for circuit designers. Effects on resistors, capacitors, bi-solar transistors, diodes, integrated circuits, SCR's, etc. are included. Effects on plastic and elastic micro materials for space systems are given. System and circuit hardening concepts are presented.													
H.6-32	AIAA 8th Electronic Propulsion Conference Title: High Voltage Solar Arrays with Integral Power Conditioning	Sept 1970	Feasibility of high voltage solar cell groupings and switches (integral with solar panel) which are integral with the solar panel and regulating the output power in discrete steps. Panel design and layout, techniques for regulation and power control, and the devices needed for mechanization are considered.						●							
H.6-33	AIAA 8th Electronic Propulsion Conference Title: Feasibility of High Voltage Solar Arrays	Sept 1970	Study of array capable of 15 kW at 2 to 16 kV. Plasma power losses, dielectric stresses, and questions relating to high voltage design fabrication and testing were considered. High voltage arrays require fewer power conditioning devices.						○							
H.6-34	Contract: NAS7-100 Title: Electron Spectrum Irradiations of Silicon Solar Cells		Simulated synchronous altitude trapped electron environment. Used Dynamitron particle accelerator-operating range 10^{-10} ampere to 3 ma at energies from 200 kev to 2.5 MeV. Both U.S. and foreign cells irradiated. Cell output measured as function of coverslide thickness, cell manufacturer, and backside irradiation.													
H.6-35	Title: Pulsed Xenon Solar Simulator System	1970	New optics and data acquisition subsystems added to this 4-year old system. Increased accuracy in solar simulation. Test results are comparable or superior to high altitude ground-based material sunlight testing. The simulator, hardware specification, performance characteristics, and comparison are described.											●		

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H.6-36	ASLE Proceedings Title: Transfer Film Formulation by Lubricative Composites	Aug 1971	Several families of composites were examined on a LFW-1 Tester, particularly those containing PTFE, and polyimide character and quality of films deposited on test ring by a bearing ball. High magnification photographs were used. Suitability of various materials was discussed.											●		
H.6-37 -38 -39 -40	Contract: F33615-68-C-1676 Title: Flexible Rolled-Up Solar Array (FRUSA) 11, 12, 13, 14th Quarterlies	April 1971	(Same as H.6-7 thru -13)	○								○				
	IMPERIAL CHEMICAL INDUSTRIES, LTD															
L.1-2	Materials Research and Standards Title: Creep Behavior of Polymer Films	1966	Creep-recovery tests were made on five polymer thin film materials used in computer equipment. The films were stressed in the 1000-3000 psi range at 26°C and 55% relative humidity. Polyethylene terepthalate had the best dimension stability under these conditions. An apparatus developed for these tests is described.		●											
	ION PHYSICS															
L.3-14 L.3-15	Contract: 952144 Title: Improved Solar Cell Contacting Techniques Quarterly Report #1 Final Report	April 1968 Feb 1969	Report on work done on aluminum and nickel contacted solar cells using IPC's high vacuum sputtering system. The effect of temperature cycle after sputtering is given for aluminum. Aluminum contact cells had more than 10% AMO efficiency for uncoverslipped CeO_2 antireflected coated cells. The cells showed superior results in a temp-humid environment to Ti-Ag.				○									
L.3-16 L.3-17	Contract: NAS5-10236 Title: Solar Cell Cover Glass Development Final Report (2 Vols)	March 1971	These reports describe the successful development of a practical integral coverslip technology for solar cell utilization. Program course has been identification of design considerations, development of deposition procedures, identification of the stress mechanism, examine alternative materials, fabricate and evaluate thick integral coverslips of low stress materials.			●								●		

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	UNIVERSITY OF ILLINOIS															
L.4-1	Contract: JPL 952383 Title: A Study of Irradiation-Induced Defects in Silicon Using Low Temperature Photoluminescence Final Report	May 1971	Report on research to investigate irradiation-induced defects in silicon, using low temperature photoluminescence as a probe of defect properties.													
	INTERNATIONAL R&D CO.															
L.5-1	7th Int'l Power Source Symposium Title: New Developments in Degradation Resistant CdS Solar Cells	Sept 1970	Description of cell manufacture given. Experiments leading to improvements in manufacturing technology to minimize cell instabilities are discussed. Degradation of output on exposure to illumination or on thermal cycling are reviewed in light of improvements.													
	INGENIEURBURO SHCEEL															
L.6-1	11th European Space Symposium Title: Development of Low Cost Solar Array for Spacecraft	May 1971	Flexible array unfolding from a spacecraft by the centrifugal force of spinning is reported. Costs are diminished and the power to weight ratio of the array are bettered by a factor of two. Tests to evaluate the dynamics and damping of the unfolding process are described.													
	JAPAN															
J.1-2	Japanese Journal of Applied Physics Title: Effects of Impurities on the Radiation Damage and Annealing Behavior of Si Solar Cells	Sept 1970	Paper which examines both the radiation damage and subsequent isochronal annealing properties in Cu or Ni-doped N/P and P/N-type cells, and to fabricate the greater radiation-resistant solar cell.													
J.1-3	Electronic Communication in Japan Title: Curve Power Factors and Radiation-Induced Changes Therein in Silicon Photovoltaic Cells	1970	Article which obtains curve power factors by experiment and calculation. CPF decrease as junction depth, bulk resistivity, and temperature decrease, and increase as illuminating light intensity increases. Degradation of CPF of Ni or Cu doped cells by Y-radiation is less than in non-doped specimen.													
	JOHNS HOPKINS UNIVERSITY															
J.2-7	Title: Design and Test of the SAS-A Power System	May 1970	Report on the design and test of the SAS-A power system which contains a solar cell array, a rechargeable nickel-cadmium battery, and two redundant charge control systems.											●		

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J.2-8	TG 1103 Title: Solar Panel Test Set	Feb 1970	Development for testing solar cell panels in artificial sunlight at an equivalent intensity of 140 mW/cm^2, iodine-quartz (tungsten) lamps as source. Air conditioner supplies cooling air for temperature control of the solar panel under test. Test set calibration methods are described.														
	LTV AEROSPACE																
L.1-2	Title: Advanced Spacecraft Electrical Power Systems, Applying Solid State Technology Final Report	Dec 1970	Report on a study to develop advanced approaches to solid state power switching, solid state circuit protection, signal processing, control logic, and multiplexing for application to advanced power distribution and control systems. Three concepts were investigated: system using electromechanical switches, relays and circuit breakers; hybrid system (electromechanical and solid state); and a solid state system. The solid state was selected on basis of weight, size, EMI compatibility.						○							
	LMSCI																
L.4-28	LMSC 894048 Title: Development and Radiation Resistance Evaluation of Solar Cells with Integral Radiation Shields and Wraparound Contacts	April 1965	Proposal which is a continuance of the effort to obtain increased efficiency and output from solar cells, both from a weight and cost viewpoint. Approach is wraparound cells, and an integral shield is to be used to protect the cell from space radiation and control operating temperature.			○		○									
L.4-29	LMSC A976178 Vol I Title: Proposal for Development of Lightweight Solar Array	Aug 1970	Proposal for the lightweight solar array program which is divided into four phases: system design study, component and modular design and testing, array fabrication and assembly, and the testing program. Also included is a program schedule.														
L.4-30	AIAA Journal Title: Comment on "Effect of Simulated Micrometeoroid Exposure on Performance of N/P Silicon Solar Cells"	Feb 1968	Inconsistency of recently published data is pointed out. Micrometeoroid flux models used require updating to yield updated damage predictions.														
L.4-31	Contract: NAS5-11637 Title: Passive Solar Array Orientation System (Thermal Heliotrope) First Quarterly Report	Dec-March 1969	Report on progress to develop a thermally actuated sun-tracking system using bimetal elements for both sensing and motive power. Exploration consists of a survey of general tracking requirements, study of thermal heliotrope operating mechanisms, analyze thermal properties, fabricate and test models in simulated orbit environments; document findings and recommendations.											●			

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L.4-32	MRI 503.02 Title: Lubrication Evaluation Final Report	April 1968	A summarization of lubricants for spacecraft operation which was evaluated by Materials Science Laboratory and other groups. Information is presented on performance of various oils, greases, bonded solid film lubricants, and special self-lubricating retainer materials on instrument size ball bearings in simulated space conditions.													
L.4-33	Technical Note Title: Combined Exponential and Wearout Reliability Analysis for Intelsat V Satellite LMSC/A989975	April 1971	A mathematical presentation of long life satellite wearout and its relationships to exponential reliability prediction results. This report also discusses the practical implications of the assumption of delayed onset of wearout as it affects system design policy.													
L.4-34	Contract: NAS3-14398 Title: Investigation of FEP Teflon as a Cover for Silicon Solar Cells	Aug 1971	A program which would demonstrate the feasibility of using FEP teflon as a cover for silicon solar cells. Type C FEP was heat sealed to cells and the progress was optimized. Abbreviated and extended thermal tests were conducted. The effects of high humidity and temperature, thermal shock, and ultraviolet proton and electron irradiation were evaluated.			●										
L.4-35	Contract: NAS5-11236 Proceedings: Thermodynamics, Thermoplastics of Space Flights Title: Thermal Analysis of the 14-foot Deployable Parabolic Antenna	March 1970	This is a thermal analysis of a 14-foot deployable parabolic reflector. The influence of RTG's extended on booms upon the rib and mesh panel temperatures was determined. Analysis was conducted at 1 AU, 10 AU, and 30 AU distances and at various angles with respect to the sun. Thermal distortion predicted for the antenna was small to assure satisfactory RF performance.													○
L.4-36	National Symposium on Natural and Man Made Radiation in Space Title: Low-Energy Radiation Environment at Synchronous Altitude	March 1971	A data analysis on data gathered from the ATS-5 launched into synchronous orbit which contained instrumentation for the investigation of the plasma properties at low energy charged particles (1-50 keV). Analysis showed a systematical variation in the average low-energy particle environment at synchronous altitude with local time and magnetic activity. Suggestion of a possible ability to predict the environment under various conditions.													

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L.4-37	MRI 630.00 Title: Flexible Printed Circuitry for Solar Arrays	Dec 1971	Description of a program to develop fabrication techniques of large flexible copper conductor solar array substrates. The arrays (assembled by lamination) are made of layers of FEP and polyimide enclosing a copper printed circuit. Also, there is a discussion of the use of molybdenum or aluminum conductors instead of coppers, although the use of these materials is not recommended.		●											
L.4-38	Thermal Control Working Group Meeting Title: Recent Coating Developments and Exposure Parameters	Aug 1967	Recent thermal control material exposure parameters and coating developments are reported. The damaging constituents of the total space environment are summarized. Recent in situ data for selected materials exposed to UV and charged particles plus UV is presented.													
L.4-39	Contract: AF04(657)-787 Title: Irradiation of Solar Cell Cover Slides and Adhesives with 1.5 MeV Electrons	Aug 1964	Description of experiment complements a previous effort using UV on three candidate adhesives for solar cell cover material. Results of irradiation of two cover slides materials using three adhesives is reported.			○										
L.4-40	Title: Evaluation of Optical Properties and Environmental Stability of Solar Cell Adhesives	Apr 1964	Results of exposure to UV radiation in air or transparent silicon and epoxy covering adhesives is reported. Environmental conditions (thermal cycling, hot and cold soak, and humidity) also applied. Optical properties and mechanical integrity of laminated test specimens are reported.													
L.4-41	Contract: NAS8-26004 Title: Investigation of Transient Degradation/ Contamination of Thermal Coatings Monthly No. 5	Nov 1970	10 year life-time space station candidate thermal control materials investigated for contamination by vacuum, UV proton, and electron exposure. Effects of rocket exhaust products, waste dumps, and fuel leakage also reported.													
L.4-42	Contract: NAS3-14398 Title: Investigation of FEP Teflon as a Cover for Silicon Solar Cells	Aug 1971	Feasibility demonstration of using FEP teflon as cell cover. Process for heat sealing to cells developed. Effects of high humidity and temperature, thermal shock, and UV, proton, and electron irradiation on the bond also evaluated. Compared favorably to conventional cover glasses.													
L.4-43	Manufacturing Process Standard (Internal Document) 601C Title: Flexible Circuitry		Consolidation of manufacturing process, inspection, materials handling and packaging machinery equipment and tooling standards, tool codes, and work measurement standard data for fabrication of flexible circuitry.		○		○							●		

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L.4-45	5th Aeromechanisms Symposium Title: A Release Mechanism with Mechanical Redundancy	June 1970	SERT-2 satellite release mechanism achieving high reliability is described. Principle of operation, design details, and test program are discussed. Examples of developmental and proposed alternate configurations are also included.													
L.4-46	Contract: NAS8-26004 Title: Investigation of Transient Degradation Contamination of Thermal Coatings Monthly #4	Sept 1970	Establishment of sources and extent of degradation/contamination of thermal control materials for ten-year space missions related to space station requirements UV radiation; proton bombardment, plume infringement, waste dump, and craft leakage were some of the contaminants considered.													
L.4-47	Contract: NAS9-11039 Title: Evaluation of Space Station Solar Array Technology and Recommended Advanced Development Program	Dec 1970	Study of the feasibility of developing a 10,000 ft^2 solar array. Baseline design, fabrication, and ground demonstration of one array quadrant deployment and retraction. This document contains a review of all flexible array packaging, deployment, and retraction techniques from 1965-1970.	○	●	●	●	●		●	●	●		●	●	●
L.4-48	Contract: NAS9-11039 Title: Design and Analysis-Space Station Solar Array Technology Evaluation	Nov 1971	Baseline design description of space station solar array. Support design analyses contained in appendices. Trade studies and solutions to engineering design problems are discussed. Detailed layout drawings of major hardware components are presented.	●	●	●	●	●		●	●	●	●	●	●	●
L.4-49	Contract: NAS9-11039 Title: Tensile and Tear Tests-Solar Cell Substrate	Dec 1971	Determination, by design support tests, of tensile strength, modulus of elasticity, ultimate elongation and tear strength of candidate substrate materials. All samples identified along with properties. Test set-ups and results are described.		●		●	●								
L.4-50	Contract: NAS9-11039 Title: Creep Tests-Solar Cell Substrate	April 1972	Creep tests conducted only at steady state temperature region under maximum expected loads defined by space station requirements. Test specimens and test apparatus are described. Test results are presented in curves and discussion of hysteresis characterization.		●		●	●								
L.4-51	IECEC Paper Title: Large Array Wraparound Contact Silicon Solar Cell, Application and Development	Sept 1972	Wraparound cell offers a plausible solution to various array problems – series tab susceptibility to stress relief forming and soldering, packaging and cleaning which increases cost, cell top contact prevents total cell coverage by filter increasing vulnerability to radiation degradation.				●	●								

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L.4-52	Aerospace Mechanism Symposium Paper Title: An Artificial "G" 928 m^2 Solar Array	Aug 1972	The requirements for a 928 square meter array, its design, and finally a fullscale demonstration of one quadrant (232 sq meters) deployed in a one "g" field and described.							●	●	●		●		
L.4-53	IECEC Paper Title: Configuration Survey of Lightweight Solar Array Power Systems for Future Missions	Sept 1972	Mission reviewed represents a wide diversity of power levels, array sizes, constraints, and provide this requirement base for assessing modularity of the solar array. Solar arrays are identified and categorized. System weights are presented and power density range (watts/pound) are identified.													
L.4-54	IECEC Paper Title: Progress Report, Space Station Solar Array Program	Sept 1972	Principal goal of this program to determine the feasibility of designing and building extremely large area solar arrays, both deployable and retractable. The technology evaluation design and analysis, hardware fabrication, and testing phases are all briefly discussed.													
L.4-55	IECEC Paper Title: Design and Development of a Lightweight Flexible Solar Array Compatible with Mass Production Techniques	Sept 1972	The design and material selection for the basic electrical module are described. Implementation of future mass production and automation as a key to lower costs is discussed. Various features of flexible arrays which simplified assembly steps and minimized repair.		○	○	○	○								
L.4-56	IECEC Paper Title: System Design Considerations for a 25 Kw Space Station Power System	Sept 1972	Solar array designs for both MSFC and MSC Space Station concepts were used to generate a system weight model. With this model, alternate system design approaches are considered and evaluated. Results of this study indicated that photovoltaic power systems have weights and performance consistent with shuttle-launched Space Station requirements.													
L.4-57	Contract: NAS9-11039 Title: Design Support and Major Hardware Testing – Space Station Solar Array Program	Aug 1972	LMSC/D153526. All tests conducted under this two-year NASA-MSC contract are described. Test set-ups and resulting data are presented along with recommended additional testing that should be performed to confirm the baseline design.		●	●	●	●		●	●	●	●	●		●
L.4-58	Contract: NAS9-11039 Title: Temperature Cycling Plan for Solar Array Specimens	Aug 1972	LMSC/D159198. Reviews all temperature cycling programs currently active. A survey of best facilities is presented. A facility for testing "in situ" is described. Lockheed has initiated construction of such a test facility.													

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	LOCKHEED-GEORGIA NUCLEAR LAB.															
L.5-1	Contract: 952586 (JPL) Title: Study of the Effects of Radiation on Lithium-Doped Solar Cells	May 1970	This report describes facilities to be used in an experimental investigation of the effects of electron radiation on Lithium P/N solar cells. The environmental chamber, data collection system, light source, electron source, temperature control system, and solar cell characteristics are discussed.													
L.5-2	Contract: 952586 (JPL) Title: The Effects of Radiation on Lithium-Doped Solar Cells Final Report	July 1971	A report which describes irradiation of lithium-doped P/N cells at temperatures of 223°, 303°K. This was done in vacuum, and the source was 90 Sr beta particles at a rate of $10^{12}e/cm^2/day$. Radiation fluence was $2 \times 10^{14}e/cm^2$. Comparison was made with conventional N/P cells. Results: crucible grown LL-cells are superior at 353°K, float zone grown Li-diffused cells are slightly superior at 303°, and 223°K.													
	MARTIN MARIETTA															
M.1-9 and M.1-10	Contract: DAAB07-70-C-0304 Title: Reliable Flat Cable Conductors, Semiannual Report	Jan 1971	Test and evaluation of ITT Cannon 'FC' connectors and Microdot (MCD) connectors by USAFCOM. Test Plan is based on the requirements of MIL-C-55544, with tests such as vibration at -65°C and random vibration. No major deficiencies in either connector design have been discovered to date.												○	
M.1-11	Contract: NAS8-26114 Title: Design Development, Manufacture, Test, and Delivery of Devices for Connection of Solar Panel Circuitry to Flat Conductor Cable Solar Cell Array Harness	Oct 1971	Problems in design of such a connector are investigated. Sketches, drawings, and photos of several concepts are presented. A four-contact connector with a plastic draw latch was developed and tested. Prototype test results are presented.												○	
	McDONNELL DOUGLAS/ ASTRONAUTICAL															
M.2-3	21st International Astronautical Congress Title: Selection of an Electrical Power System for the Earth Orbital Space Station	Sept 1970	Three sources of power are evaluated in terms of criteria generated by the sources structural configuration, design of other subsystems, on board operations, and launch and resupply activities. The three systems are: nuclear reactors, radioisotopes, and solar energy. Advantages and disadvantages of each are presented in light of the above criteria.											●		

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M.2-4	ASME Publication Title: Solar-Cell/Battery Systems Research and Development for Post-1975 Satellites and Manned Missions	June 1970	Presentation of analysis and hardware tests of designs which affect the integration of the Solar Cell/Battery system for 1975 space stations. Tests are in four areas: the development of a power system evaluator, thermal control of NiCd batteries, structural integrity of light-weight rigid solar-cell panels, and analysis of roll-out solar cell arrays.													
M.2-5	Contract: NAS8-20751 Title: Flat Cable Applications Engineering Study. Final Report Phase III Volume I	July 1968	Report on tasks performed under this contract. The major tasks were to develop a practical, efficient, and reliable shielded flat-cable and termination method. Establish specifications for production type, flat cable system components which meet or exceed aerospace requirements and prepare a flat cable handbook suitable for use by all engineering, manufacturing, and inspection technologies.												○	
M.2-6	Oklahoma State University Applied Mechanism Conference, Proceedings Title: Deployable Meteoroid Shield, Saturn I Workshop	1969	Discussion of design philosophy and trade studies in the development of a deployable meteoroid shield for the Saturn I Workshop. Also this paper contains a discussion of the kinematics, resulting hardware, and a brief summary of the testing conducted at the company's Hypervelocity Ballistics Range.													
M.2-7	ASME Publication Title: Solar/Cell Battery Systems Research and Development for Post 1975 Satellites and Manned Missions	June 1970	Presentation of analysis and hardware tests of designs which affect the integration of the Solar Cell/Battery system for 1975 space stations. Tests are in four areas: the development of a power system evaluator, thermal control of NiCd batteries, structural integrity of light-weight rigid solar-cell panels, and analysis of roll-out solar cell arrays.													
M.2-8	IECEC Paper Title: Integration of Large Power Systems to Manned Space Station	Aug 1968	Design factors and system characteristics are explored. Impact of power system selection on space station is outlined. Comparison of candidate systems based on space station models for 90-day to 5-year mission durations in the 1970's with 4- to 9-man crews. Power levels from 3 to 50 kWe.	○						○						○

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	MIT															
M.4-6	Title: A High Voltage, Low Current Power Source for Long Term Space Applications	June 1970	Thesis on work done on a high voltage low current (μ amp) power source. Voltage is in the 10 KV range. Device produces voltage directly from radioactive material by collecting Beta particles emitted by the source material						○							
M.4-7	Title: Degradation of CdS Thin Film Solar Cells in Different Environments	Nov 1970	Work done on CdS thin film cells operated six months. Environment was thermal cycling between ~160°C and 60°C, constant illumination in vacuum and in dry oxygen at 60°C. These were compared to cells in synchronous orbit. Observed changes in I-V characteristics are mainly due to light and temperature effects and not by purely thermal stress.													
M.4-8	Contract 952936 Title: Radiation Damage Annealing Kinetics in Lithium-Diffused Silicon Solar Cells	July 1971	Discussion of a development of a model for the annealing kinetics of radiation damage in lithium-diffused silicon solar cells using a phenomenological approach. Carrier recombination rate is found with Shockley-Reed-Hall theory of Carrier life time. Annealing process is according to the kinetic equations of Fang. Simplifications of the above theories were made and programmed on a computer to predict cell performance.													
M.4-9	IEE Transactions on Aerospace and Electronic Systems Title: Structural Failures in Lightweight Solar Cell Arrays Under Thermal Cycling	July 1971	Different types of solar arrays mounted on honeycomb panels and flexible substrates were given thermal cycling tests between -160°C and 60°C in dry nitrogen. They were also immersed in liquid nitrogen and given vibration and fatigue tests. The arrays experienced output reduction due to contact failure, fracture in the silicon and coverslide, and disintegration of the honeycomb.													
M.4-10	TR-476 Title: Balloon Flight Instrumentation for Solar Cell Measurements	Jan 1970	Automatic I-V characteristics measured and transmitted via RF telemetry link for number (64) of cells (silicon, CdS and CdTe) aboard the high altitude JPL balloon. Measurement accuracies are 0.03 percent of full scale for voltage and 0.1 percent for current. Techniques can be used for ground or satellite application.					○						●		

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M.4-9	Air Force Contract Title: Structural Failures in Lightweight Solar Cell Arrays Under Thermal Cycling	1970	Different types of silicon cell arrays, mounted on lightweight honeycomb panels and on flexible substrates, subjected to long term thermal cycling tests between -150°C and 60°C in dry nitrogen. Liquid nitrogen immersion and vibration fatigue tests included. Failure modes caused by different cells and interconnects are compared.													
M.4-10	AIAA 3rd Communications Satellite System Conf. Title: Preliminary Results from LES-6 Solar Cell Experiment	Apr 1970	Experiment on LES-6 consists of 30 cells of various types. One year observation results are discussed. Degradations due to low energy proton damage are reported.					○								
M.4-11	Contract: AF19(628)-5167 TR-443 Title: Charged Particle Radiation Environment in Synchronous Orbit	May 1968	Composition, intensity, energy spectrum of charged particle radiation environment at sync orbit are described. Data are based on measurements from satellites. Time-averaged data in a form useful for predicting long term radiation environment to which satellites are exposed.													
	NASA/AMES															
N.1-6	Title: Instability of Slender Thin-Walled Booms Due to Thermally Induced Bending Moments	May 1970	Investigation of the instability of thin-walled booms illuminated by thermal radiation. It is assumed that the cross section is thermally seamless and thermal torques are negligible. Study is on the effect of thermally induced bending moments. A damper in the form of a closed vessel rigidly attached to the boom tip, and containing a ball free to move through a viscous fluid, is an effective stabilizer for a large class of booms in space applications.													○
N.1-7	Contract: NAS2-5516 Title: Silicon Solar Cell Development for Low Temperature and Low Illumination Intensity Operation	June 1969 Apr 1970	Influences of factors which degrade cell performance at low temperatures and low illumination intensity are examined. These causes, which include the effects of Schottley barrier rectification at back contacts, have been identified and output maximization is under way for a -135°C, 1/26 solar constant illumination cell.													

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	NASA GODDARD															
N.2-17	ASTM/IES/A2AA 5th Space Simulation Conference Title: The Interaction of Low Energy Electrons with Polymeric Per-fluorinated Ethylene-propylene (FEP)	Sept 1970	30 Kev electrons on FEP produced Lichtenberg patterns, bubbles, and buckling effects. An explanation, using theoretical analysis based on diffusion mechanism for charge flow using beam current as a source term. Expressions are given for surface charge storage and voltage across the sample. Buckling is treated using the Helmholtz free energy. *Electrolysis is postulated via a mechanism* selecting the tertiary carbon as the active site for mobile moiety generation.													
N.2-18	Title: An Analysis of Thermally Induced Oscillations of Stem-Type Booms	1969	Discussion of static, thermal bending analysis of Stem-type booms. The three booms discussed were found to be unstable in a solar environment and should be replaced by torsionally rigid booms.													●
N.2-19	IEEE Transactions on Aerospace and Electronic Systems Title: Highlights of a Brushless Direct-Drive Solar Array Control *System Design*	Apr 1970	A paper which describes a system for positioning and rate of solar power array in orbiting spacecraft. The system, which is liberated *of gears and sliding contact elements, consists* of three new major components. These are: a brushless DC torque motor, a rotary power transformer, and an offset-tooth shaft position and rate sensor. The system offers a relatively high stiffness and can be operated at indefinitely low analyzer rates with minimum power consumption.												○	
N.2-20	Telecommunications Journal – Volume 38 Title: Electric Power for Space Satellites	1971	Discussion of typical electrical power systems used onboard spacecraft briefly describes the systems which have been used, such as battery only units and nuclear energy, but the paper dwells mostly on solar energy power systems. Description of a typical solar power system *as well as a solar direct energy transfer* power system is included in this presentation.													
N.2-21	Title: Thermal Cycling Effects on Solar Cell Interconnection Tabs on an OAO-B Sample Module	July 1971	Thermal cycling tests in air were performed on solar cell interconnection tabs intentionally bent with the cycle swing from +104°C to -60°C. After 300 cycles, cracking failure occurred at the end adjacent to the solder joint that resulted in a high failure development and detect rate. Similar tests on flight paddles performed in vacuum showed lower failure rate, and the major failure mode was the solder joint. Therefore the test was not a good prediction of flight paddle performance. However, a redesign of tabs is recommended.				●						●			

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N.2-22	NASA TMX-67848 Title: The Status of Cu_2S-CdS Solar Cell Development	May 1971	Paper which describes work to develop a low cost alternative to silicon solar cells using thin film Cu_2S-CdS. The main problems are reproducibility and degradation in a simulated space environment. The performance of current production cells and results of environmental tests are presented. Solutions to some past problems are discussed.													
N.2-23	7th Photovoltaic Specialist Conference Title: Solar Array Shadowing Analysis and Design Accommodation	1968	Analytical approach developed based on IMP-1 loop antenna shadowing across solar panels. Test indicate that for an array analysis, the voltage drop associated with shadowing can be neglected and that umbra shadow effect on a single cell and a parallel group of cells is approximately equivalent. Power output determined by ratio of shadowed to unshadowed active cell area.	○				○								
N.2-24	TMX 65610 Title: Solar Cell Data from the Radiation Damage Experiment on Satellite ATS-1	May 1971	Presented results in tabular and graphic forms of voltage currents characteristics of 29 solar cells during 418 days in synchronous orbit. Cells had shields of several kinds and thicknesses. The apparatus, orbit, data processing, and conclusions are described.													
N.2-25	X-716-68-204 Title: Photovoltaic Properties of US & European Silicon Cells under 1 MeV Electron Irradiation	Apr 1968	Irradiation by means of Van de Graaf generators. Specimens manufactured in 1966-1967. Various cells and their associated radiation affects are compared, facilitated by inclusion of open circuit voltage and short-circuit data in tabular form.													
	NASA HEADQUARTERS															
N.3-2	NASA SP-3024 Title: Models of the Trapped Radiation Environment Volume I – Inner Zone Protons & Electrons Volume II – Inner and Outer Zone Electrons Volume V – Inner Belt Protons Volume VI – High Energy Protons	1966	Four volumes which present data collected by satellites. Data is of the flux and energy spectra of protons and electrons trapped in the geomagnetic field. Information is used to construct a model environment.													

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N.3-3	Mechanical Engineering Publication. Title: Energetics 5: Photovoltaic Power	Oct 1966	Discussion of the development of photovoltaic devices from the early selenium type to the present day silicon solar cell. Discusses the characteristics as well as projecting future work in the area.													
N.3-4	Patent Application 3,238,774 Title: Pressurized Cell Micrometeroid Detector	Mar 1966	Invention which has the object to provide a micrometeroid detector that will give a direct measurement of the micrometeroid hazard to thin structural materials used in space vehicles. This includes a description of how it works.													
N.3-5	Title: Advanced Technology Requirements	June 1970	Discussion on the impact of space station concepts on technology required for the program. Impact is both on design of the basic components and also on test qualification.	○												
N.3-6	IEEE Transactions on Aerospace and Electronic Systems Title: Status of Photovoltaic Solar Energy Converters	Aug 1965	This paper is a discussion of the state of the art in solar cells and their modules and mountings. Also included is a discussion of performance characteristics and recommendation for further development.													
N.3-7	NASA SP-8074 Title: Spacecraft Solar Cell Arrays Monograph	May 1971	Organizes and presents for effective use in design the significant expenditure and knowledge in this field, accumulated to date. State-of-the-art, design criteria, and recommended practices are described. It is not intended to be a design handbook or manual.			○		○								
N.3-8	AIAA Electronic Power Committee Assessment Title: Electrical Power Systems for Space Achievements & Issues	Aug 1971	Technology progress in fuel cells, batteries, solar cell arrays, RTG's, is presented. Applications in the 1970's at various power levels are discussed.													
	NASA JPL															
N.4-24	ASME Publication Title: Solar-Panel Approaches for a Venus-Mercury Fly-by	June 1970	Paper which discusses the problems associated with the Venus-Mercury fly-by, because flat, fully celled solar panels will exceed their maximum operating temperatures; it discusses techniques used to evaluate the temperature and power performance of solar array designs considered for the mission; also, a comparison of the predicted performance of 3 design types.											●		

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N.4-25	AIAA Paper Title: Characteristics, Capabilities, and Costs of Solar Electric Spacecraft for Planetary Missions	Dec 1970	A paper which presents the current estimate of the characteristics, capabilities, and costs of solar electric propulsion. The results obtained use a set of assumptions and input parameters and no more than three computer programs. Various missions were then ran comparing solar electric propulsion with conventional ballistic propulsion.													
N.4-26	Patent Application Title: Deployable Support	April 1970	Invention for an improved deployable support particularly suited for use in supporting arrays of solar cells suspended in a cantilever fashion from an operative spacecraft.											○		○
N.4-27	TR-32-1519 Title: Lightweight Solar Panel Development	March 1971	Report of technical information concerning the preliminary design, analysis, test article design, fabrication, and test of a lightweight solar panel made of a beryllium structure with an active cell area of 24 ft^2. Results are presented of the modal survey, reverberant acoustic, random vibration, sinusoidal vibration, static load, thermal-vacuum-shock, substrate frequency, and power output tests.													
N.4-28	Title: XII Electronic Packaging and Cabling	Oct 1970	An evaluation to determine the electrical, mechanical, and handling properties and specific environmental influence characteristics of several small-gauge electrical wire types. Investigation was in three parts. First, there were preliminary screening tests; second, samples were subjected to detailed series of electrical, dimensional, physical, and handling property tests; third, selected environmental tests were performed.												○	
N.4-29	TR 32-1502 Title: Parametric Study of the Performance Characteristics and Weight Variations of Large-Area Roll-Up Solar Arrays	Dec 1970	This paper is an analysis to determine the relationship between the performance characteristics of large-area roll-up solar arrays of the single boom, tensional substrate design.													
N.4-30	TR-32-1530 Title: Results of the 1969 Balloon Flight Solar Cell Standardization Program	May 1971	A description of calibration tests conducted on free-flight balloons. These tests were done on silicon cells, then, once recovered, are to be used as intensity references in solar simulators and in terrestrial sunlight. Sky radiation experiments were also conducted, indicating that there is no detectable sky radiation at 36,576m.					○								

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N. 4-31	TR 32-1528 Title: Structural Analysis of Silicon Solar Arrays	May 1971	This is a report on the structural design of solar arrays; areas of investigation include thermal stresses in array components, mechanical stresses in solar arrays, analysis of a stress relief interconnect, and current material properties. Emphasis is on development of simple, accurate methods of analysis.				○	○								
N. 4-32	JPL Space Program Summary 3D-66 Volume III Title: X Spacecraft Control. The Attitude Control of a Flexible Solar Electric Spacecraft	No Date	Theoretical analysis of the solar-electric powered spacecraft design. A study of the attitude control during its thrust phase. The mathematical exploration revealed that flexible solar arrays were not detrimental to controlling the attitude. It is also shown that the "tail-wags-dog" effects on attitude control were minor.													
N. 4-34	TR 32-1514 Contract: NAS7-100 Title: Effects of Lithium Doping on the Behavior of Silicon and Silicon Solar Cells	Feb 1971	Author's interpretation of results of industry programs to improve the radiation resistance of silicon solar cells by the use of lithium doping. The major conclusions reached are presented as well as suggestions for future work. It appears that lithium doped cells give better efficiencies than efficiencies of the state-of-the-art N/P cells after exposure to high fluences of 1 MeV electrons and neutrons.													
N. 4-35	TM 33-464 Title: Capacitance of Solar Cells and Panels Under Various Load Conditions	Feb 1971	The diffusion capacitance of a solar cell has been found to be directly proportional to the short circuit current. In order to reduce error in readings caused by this capacitance when measuring the power capability of a cell by the sweep loading technique, the amount of capacitance must be known. This report presents values one can expect as well as measurement techniques.						●							
N. 4-36	Patent Application 3,466,189 Title: Solar Cell Matrix	Sept 1969	A configuration of a solar cell matrix for connecting cells in parallel to form a submodule, which in turn can be connected in series to form a cell matrix.				○									

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N. 4-37	Patent Application 3,473,758 Title: Roll-Up Solar Array	Oct 1969	A novel solar array arrangement which allows the array to be rolled up on a drum at launch and to be deployed when the spacecraft is in outer space. An arcuate hollow beam along each panel edge stiffens the cantilevered panel. The beams are flattened when they are rolled up and return to their hollow shape as they are uncoiled.													○
N. 4-38	TR 32-1519 JPL Contract 52571 Title: Lightweight Solar Panel Development	March 1971	Description of work performed under that lightweight solar panel development program. This report contains technical information concerning the preliminary design, analysis, test article design, fabrication, and test of lightweight solar panels made of a built up beryllium structure with an active cell area of 29 ft^2.													
N. 4-39	NASA JPL Tech Brief Title: Environmental Effects on Silicon Solar Cells	Aug 1971	Report on tests performed on batches of cells having titanium silver contacts with and without solder coating to determine the effects of environments on the mechanical and electrical properties of the cells. It was found that the presence of solder coating on solar cells can have a protective or deleterious effect, depending on the environment.													
N. 4-40	TM 33-495 Title: Solar Cell Performance of Temperature and Illumination of Angle of Incidence	Sept 1971	Measurement of response of solar cells to non-normal illumination. Heliostat in JPL celestarium was used to calibrate ATS-E experimental panels. Results of this testing and comparison with a simple theory are presented.													
N. 4-41	TR 32-1541 Title: Effects of Storage Temperatures on Silicon Solar Cell Contacts	Oct 1971	Cells with various contact systems and configurations (silver titanium, silver titanium with solar coating, silver titanium with palladium and electroless nickel) were investigated, heat soaked at 150°C temperature. Electrical and mechanical contact stability determined under high humidity and higher temperature conditions.				○									
N. 4-42	TM 33-497 Title: Supporting Data Package for TR 32-1541. Effects of Storage Temperatures on Silicon Solar Cell Contacts	Oct 1971	Cells with various contact systems and configurations (silver titanium, silver titanium with solar coating, silver titanium with palladium and electroless nickel) were investigated, heat soaked at 150°C temperature. Electrical and mechanical contact stability determined under high humidity and higher temperature conditions.				○									

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N. 4-43	Title: Results of the 1969 Balloon Flight Solar Cell Standardization Program	May 1971	A description of calibration tests conducted on free-flight balloons. These tests were done on silicon cells, then, once covered, are to be used as intensity references in solar simulators and in terrestial sunlight. Sky radiation experiments were also conducted indicating that there is no detectable sky radiation at 36,576m.					○								
N. 4-44	TM-33-476 Title: Computation of Structural Modes of a Roll-Out Array Spacecraft for Attitude Control Study	May 1971	A study of the structural modes required to determine the interaction between an attitude control system and a flexible structure. The flexible structure considered has a low stiffness that leads to natural frequencies in the range of the frequency response attitude control system, producing a coupling between the response of the structure and the attitude control system.												○	
N. 4-45 and N. 4-46	TM 33-473 Title: Measured Performance of Silicon Solar Cell Assemblies Designed for Use at High Solar Intensities	March 1971	Data are presented on three solar cell panel design approaches for use at high solar intensities. They are; the second surface mirror mosaic approach, the selective band-pass filter approach, and the tilted panel approach.			●										
N. 4-47	NASA Case NPO-11190 Patent Title: Solar Cell Matrix	Feb 1971	Invention relating to an improved solar cell matrix comprising a multiplicity of separately protected solar cells. Each cell is individually encapsulated allowing the cell to be protected against accidental impact and a deposition of contaminants.													
N. 4-48	5th Aerospace Mechanism Symposium Title: Damper Design From a Structural Viewpoint	June 1970	Nonlinear structural analysis of Mariner spacecraft's solar panel system. Some solar panel tip dampers bottomed at a certain frequency, attributable to a "jump" phenomenon which can result when a damper's response is not single-value at same frequency.	○												●
N. 4-49	NASA-JPL Note to MSC ad HOC Solar Array Advisory Committee: Thermal Cycling	Sept 1970	Presents a disturbing picture of the present status of the technology and suggests a program to obtain technology readiness for an array which must survive thousands of thermal cycles from +70°C to -150°C.	●										●		

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N. 4-50	JPL Space Programs Summaries Volume III 37-62 37-65	April and Oct 1970	Program subjects treated: Solar Cell Standardization Radiation Damage in Li-doped Silicon Structural Damage in Li-doped Silicon By Neutrons Radiation Damage in Li-doped Silicon By Infrared Improved Cell Contact-Interconnect Mariner Venus-Mercury Components Irradiation Lightweight Solar Panel Development				○	○								
N. 4-51	Patent Application 3534376 *Title: High Impact Antenna*	Oct 1970	Consists of cup, whose open end defines the antennas' radiating aperture. A probe which is energized with microwave energy is positioned within the cup parallel to cup's shorted end at a selected distance therefrom. Dielectric material fills the cup to support the probe and strengthen the side walls etc.													
N. 4-52	Patent Application NPO 11361 Title: Single Curved Reflector for Use in High Gain Antennas	Feb 1971	Furlable primary reflector having a frusto-conical, singly-curved reflective surface operatively associated with a point-source feed. The reflective surface of the reflector plate (deployed) defines a frustrum and is employed with a coaxially aligned secondary reflector.													
N. 4-53	9th Photovoltaic Specialized Conference Title: Stress Analysis & Design of Silicon Solar Cell Arrays are Related	May 1972	Compilation of mechanical and thermal material properties of the components of solar cell array. Potential failure areas in various design configurations in a given thermal environment are discussed. Guidelines and means to optimize a given design are illustrated.													
N. 5-2	NASA-LANGLEY TN D-6024 Title: Effect of Radiation on Cerium Doped Solar Cell Cover Glass	Dec 1970	Results of an investigation to determine the feasibility of using an inexpensive radiation resistant solar cell coverglass to replace synethetic fused quartz. Samples irradiated with 1 MeV electrons on 22 MeV protons. Cerium doping (1 to 2 percent by weight) improves radiation resistance.			○										
N. 5-3	Patent 3,350,034 Title: Satellite Appendage Tie-down Cord	Oct 1965	Tie-down cable having an elastic nylon cord within a fiberglass covering of slightly larger length to absorb circumferential expansion of the spacecraft rocket booster and maintain the appendages in a packaged condition.													

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N.5-4	5th Aerospace Mechanism Symposium Title: Nutation Dampers for Manned Spacecraft	June 1970	ND's examined from standpoint of application to manned Space Stations with artificial "g". Typical spacecraft concepts and associated control requirements are considered. Examples proposed.													
N.5-6	NASA SP 8063 Title: Lubrication Friction and Wear	June 1971	Guide to formulation of design requirements and specifications by NASA. Presents the state-of-the-art, criteria imposed to ensure light-worthiness, and recommended practices to satisfy the criteria.													
	NASA LERC															
N.6-24	TMX 2142 Internal Document Title: Effects of Diffusion Redistribution of Phosphorus on the Characteristics of Si Solar Cells	Dec 1970	Cells fabricated by redistribution with and without final phosphorous exposure compared to standard saturation diffused cells. Redistribution alone produced highest short wavelength response. In deep junction, cells did not enhance response. Redistribution cells had higher sheet conductance.													
N.6-25	AIAA Journal Article Title: Effect on Surface Thermal Properties of Calibrated Exposure to Micrometeoroid Environment	Oct 1966	Targets of several metallic materials impacted by micro-size particles at hypervelocities. Then placed in solar-space-environment chamber and exposed to beam simulating solar radiation. Values of solar absorptance, hemispheric emittance, and equilibrium temperature were obtained as a function of exposure to simulated micrometeoroid impaction.													
N.6-26	AIAA Journal Article Title: Effect of Simulated Micrometeoroid Exposure on Performance of N/P Silicon Solar Cells	July 1967	Both shielded and unshielded 1 x 2 cm N/P Si solar cells bombarded by clouds of 6-μ diam SiC particles to hypervelocities (2.65Km/sec) in a shock tube. Degradation of the cells determined by measuring current-voltage characteristics before and after exposure. Expected damage to cells in near-earth space plotted based on this method.													
N.6-27	Application for Patent Title: Improved Cover for Solar Cell	April 1970	Invention concerned with protecting photovoltaic devices. Teflon FEP (commercially known) is fused directly to the surface of the solar cell. Cells so covered exhibit efficiencies in the range of 4% to 5% AMO.			●								◐		

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					SUBSTRATES	CELL COVERS	CELL INTER-CONNECT	SOLAR CELLS	POWER CONDITIONING	STOWAGE METHOD	PROTECTIVE PADDING	DEPLOY./ RETRACTION	END SUPPORT	SUPPORT STRUCTURE	POWER TRANSFER	EXTENDIBLE STRUCTURE
N.6-28	NASA TM-X-62852 Title: The Degradation of Cu ZS-CdS Thin Film Solar Cells Under Simulated Orbital Conditions	July 1970	Paper given at international colloquia on solar cells. Simulated low earth orbit condition tests on Cu_2S-CdS cells. Progressive deterioration due to internal short circuitry was observed.														
N.6-29	3rd Space Simulation Conference Title: Radiation Properties of a CdS Solar Cell and Various Metals at Space Conditions	Sept 1968	NASA-Lewis program for a new technique for measuring solar absorptance and hemispherical emittance over a wide temperature range (155°F to 520°K). Makes up for lack of theoretical methods for prediction of cell's electrical behavior.														
N.6-30	NASA TM-X-2231 Title: Test of Cadmium Sulfide Solar Cells in a Series String	May 1971	Vacuum thermal cycling test conducted. After 905 cycles, changes in cell performance were: -1.9% in max power, -2.4% in fill factor, -3.4% in short-circuit current, and 3.6% in open-circuit voltage. Correlation analysis discussed.														
N.6-31	NASA TM-X-2234 Title: SERT 2 Spacecraft Electrical Power System	March 1971	Design objectives of this 1.5 KW solar array system were demonstrated in the flight. Minimization of mission criteria component failures is discussed.														
N.6-32	NASA TM-X-2246 Title: Development History & Flight Performance of SERT 2 Solar Array	April 1971	Solar array consists of 33,000 2-by 2-cm N/P silicon cells. Electrical power at end of mission: 1100 watts at 56V for ion thruster and 180 watts at 28V for other subsystems. All requirements for the mission were met.														
N.6-33	Application for Patent #3,434,885 Title: Method of Making Electrical Contact on Silicon Solar Cell and Resultant Product	March 1969	Electrode connection for cell made by depositing a layer of cerium on cell surface and then depositing a layer of silver on the cerium. The cell with the two layers deposited thereon is then centered at a temperature between 500°C and 800°C.				○	○									
N.6-34	J. Spacecraft Article Title: FEP Encapsulated N/P Silicon Solar Cell After Simulated Micro-meteoroid Exposure	June 1971	Si cells encapsulated in FEP exposed in shock tube to 6μ silicon carbide (SiC) particles at a velocity of 2.65 Km/sec. Current voltage (I-V) curves for cells before and after impaction by filtered 600W tungsten iodine lamps. Degradation discussed.			●											

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N.6-35	NASA TM-X-2137 Title: Performance of Soldered and Cemented Cover Glass Silicon Solar Cells	Nov 1970	Method developed for soldering protective glass covers on solar cells without adhesive or ultraviolet protective filter.			○		○								
N.6-36	TM-X-67847 Title: Long Term Tests of CuZS-CdS Thin Film Solar Cells Under Simulated Orbital Conditions	1971	Test facilities are described. Results of long term thermal cycling and continuous illumination tests are presented. Cells were thermally cycled 10050 cycles. Illuminated with a xenon-arc solar simulator.													
N.6-37	TN-D-6362 Title: Shorting Path Mode of Degradation in Copper Sulfide, Cadmium Sulfide Thin Film Solar Cells	May 1971	Cells subjected to dark forward bias tests and tests under AMO illumination while in open circuit condition. Cells degraded from 20 to 50% in max power, from 5 to 10% in open-circuit voltage, and from 50 to 95% in shunt resistance.													
N.6-38	TM-X-2292 Title: Effect of Cell Vintage and Certain Testing Procedures on Degradation of Cadmium Sulfide Thin Film Solar Cells	May 1971	Vacuum thermal cycling tests performed on cells to determine the effort of four factors on cell performance. Factors were: test facility, month of cell mfg, cell electrical arrangement, and cell loading and measurement procedure.													
N.6-39	TM-X-52876 Title: Space Transportation System Technology Symposium Vol 5 Operators Maintenance & Safety	July 1970	Earth to orbit shuttle alternatives selection. Technology working groups and technology steering groups findings are reported and discussed. Illustrations and brief words of explanation of the material presented.													
N.6-40	Patent Application LEW 11065-1 Title: Attaching Cover Glasses to Solar Cells	July 1971	This invention is directed to a method of binding cover glasses to solar cells by use of a thin film of a transparent plastic material. Heat and pressure form a laminate. The binding material is unaffected by UF and does not degrade under particulate radiation bombardment.			○										
N.6-41	TM X-52870 Title: Spectral Responses of Silicon Solar Cells at Low Temperature	Aug 1970	Measured at temperatures down to 95°K with poor and good performance. Good cells showed a gradual loss in red response. Further loss in red response was responsible for rapid decrease in current. The flat spot and the loss in current appear to be related.													

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N.6-42	Title: Comparison of Lithium Containing P on N Silicon Cells with N on P Cells		Two different types of damage caused by bombardment with high energy atomic particles: (1) increase in density of recombination centers (2) decrease in diffusion length of generated changes. Long-term reliability of cells stored or operated above room temperature is poor because Lithium changes its concentration profile.													
N.6-43	TMX-52875 Title: Improvements in Silicon Solar Cell Cover Glass Assembly and Packaging Using FEP Teflon	July 1970	Two techniques described. One used teflon as an adhesive eliminating UV filter. The second uses teflon, both as cover material and as adhesive for mounting cells to flexible substrate. Characteristics of completed array are light weight, flexible, insulated, completely sealed, and breakage resistant.			○										
N.6-44	TMX-2420 Title: Performance of an Electrically Raised Synchronous Satellite when Subjected to Radiation Degradation Effects	Nov 1971	As satellite ascends through high intensity radiation belts, the solar array power, and hence ion thruster output, degrade. Performance of solar array and thermal augmented Thor/Delta launch vehicle is evaluated. Transfer times and solar array requirements are presented for payloads from 450 to 1100 kg.													
N.6-45	ASLE Proceedings Title: An Investigation of Oxidation Resistant Solid Lubrication Materials		Research on solid lubricants for use at high temperatures in air on other gaseous environments. Characteristics of oxide and fluoride lubricants at temperatures to 1700°F are described. Experience with fluoride-metal self-lubricating composites and the concept of cast, self-lubricating ceramics are described.													
N.6-46	TMX-52995 Title: Thermal Cycling Test of a Flexible Solar Cell Module	March 1971	Exposed module to temperature cycles between 87°C in simulated sunlight and -108°C in darkness at pressure of 10^{-7} Torr. Exposed test module to over 2000 cycles. Cover glasses did not crack or delaminate, soldered silver mesh interconnect did not fail. Very slight darkening of fiberglass re-enforcing Kapton substrate.		○	○	○	○								
	NAVAL RES LAB															
N.7-10	CR-109856 Title: Solar Cell Research PH 2 Semiannual Report 2 Copies	April 1970	Two major topics were investigated. (a) Effectiveness of lithium dopant in diminishing permanent radiation damage in silicon solar cells (b) influence of cryogenic temperature environment on electron radiation damage in Si solar cell. Damage to cells which were irradiated, under controlled conditions by both cobalt gamma and 1 MeV electron, is reported.											●		

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N.7-11	Radiation Effects (GB) 4 (3/4) Title: Analysis of Radiation Damage in Silicon by Thermal Annealing of Solar Cells	July 1970	Study of cell photovoltaic parameter irradiated at room temperature by electrons (15 to 45 MeV), protons (5 MeV), and fast neutrons. Boron or aluminum doped Czochralski processed cells (single crystals). Two stage annealing observed after radiation damage.													
N.7-12	Radiation Effects (GB) 4 (3/4) Title: Radiation Effects in Silicon Solar Cells	July 1970	Radiation damage induced by 1 MeV electrons in a variety of Si solar cell types as a function of dopant impurity and resistivity of the base region. Also rad damage by 0.2 MeV protons on cells with coverslips. Current voltage characteristics measured under solar simulator emitting 140 mW/cm^2 at AMO.					○								
N.7-13	IEEE Transactions on Electron Devices Vol ED-18- No. 7 Title: Radiation Damage in Silicon Solar Cells from Low Energy Protons	July 1971	Kilo volt-energy protons cause damage in small areas of cell unprotected by the coverslip in synchronous orbit. This paper reports cell current degradation at fixed voltage in nominal 10 cm cells with coverslips irradiated by 150- and 270-KeV protons.													
	NORTH AMERICAN ROCKWELL															
N.9-2	AIAA Paper – 8th Elec Prop Conf Title: Solar Array Degradation Due to Meteoroid Impacts During Extended Planetary Missions	Sept 1970	Solar electric propulsion spacecraft concept for a 1190 day asteroid belt survey – Analytical procedure developed for determining power loss due to cumulative impacts on solar cells.													
N.9-3	Contract: NAS9-10444 Title: Flat Conductor Cable Termination Development Programs	Sept 1970	Feasibility model fabrication and development tests of methods for terminating FCC to small electrical components. Screw type, solder, flattened and pierced solder terminals were evaluated. Test results show these design concepts suitable for termination.												○	
N.9-4	AIAA Paper – 8th Elec Prop Conf Title: Solar Electric Propulsion Asteroid Belt Mission	Sept 1970	Results of study of an unmanned asteroid belt probe. 10 Kw rollout solar array (rated at 1 AU). Developed SEP (solar electric propulsion) at minimum cost and selected compatible subsystem and designs.													

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	NASA-MSFC															
N.10-1	Huntsville TMX-53975 Title: Flat Conductor Cable Design Manufacture & Installation	Jan 1970	Detailed information is provided on cable connectors and support hardware, developed on various programs which were conducted and funded by NASA-Huntsville. MIL-SPEC relationship defined. Round-wire and flat-conductor cable compared.						●						●	
N.10-2	Contract: NAS8-2044 Title: Experimenters Design Handbook for the Manned Lunar Surface Program	Jan 1967	Final report of Hughes Aircraft Co. study for MSFC. Presents useful instrument design data and information for potential SKYLAB scientific/technical experimenters. Development of superior scientific instruments for future missions (cameras, sensors, gravimeters, etc.).													
N.10-3	Preliminary Copy Title: Shadow Induced Failures in OWS Solar Cell Array	Dec 1970	Investigation and analysis of these phenomena, including interconnect failure and cell breakdown caused by excessive reverse voltage biasing. Determination of seventy of "hot spots" and "voltage breakdowns" caused by open or shadowed cells. V-I characteristics of OWS type 2 x 4 cm cells discussed.	○				○								
N.10-4	TM-X-64542 Title: Contact Resistance of Electroplated Flat Conductor Cable Conductors (FCC)	July 1970	Series of tests conducted to determine the contact resistance of gold-over nickel plated and nickel-plated FCC conductors engaged with a specially prepared FCC receptacle. Tests at room atmosphere, outside winter, and 500 mating and unmating cycles showed gold-over nickel plated contact has lowest contact resistance.												○	
N.10-5	Case-MFS-20757 Title: Electrical Connector	April 1971	Invention of an electrical connector for engaging flat conductor cables with round wire cables or with other flat cables. Highly reliable electrical contact using novel design is described.												○	
N.10-6	TMS 64613 Title: Flat Conduction Cable Connector Survey of 1970	July 1971	Current and potential sources of flat conductor cable connecting and terminating devices were investigated to compile data and material into a design handbook. No attempt is made to judge the quoting or endorse any one manufacturer of FCC hardware.													

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N.11-1	NORTHERN COLLEGE CANADA Adv. Energy Conversion Title: Recent Progress of Thin Film Solar Cells	May 1967	State-of-the-art is reviewed on CdS, CdTe, and GaAs cells. Fabrication, structure, and properties of these cells are described. Solar conversion efficiency, specific power to weight ratio, and environmental stability are also discussed.													
N.12-1	NATIONAL BUREAU OF STANDARD NBS-SP-336 Title: Space Simulation	Oct 1970	Contains all papers presented at 5th Space Simulation Conference on Contamination, ablation, degradation of materials by the space environment, and predictive testing of these are discussed. Operation of space simulation facilities are described.													
N.13-1	NASA MSC-HOUSTON NAS 9-8953 MSC-04300 (Rev A) Title: Bibliography of Source Data for the Modular Space Station	July 1971	Contains a listing of the government furnished data provided for the modular space station. Program definition study (Phase B).	●												
O.1-2	OPTICAL COATING LAB Company Spec. Title: Specification for Solar Cell Covers	July 1971	An updating of specification O.1-1.			●										
O.2-1	OLIN BRASS INC. Technical Letter Title: New Printed Circuit Copper Finish for Flexible Printed Circuits	No Date	Adhesion and surface stability of the printed circuit copper is improved. Inorganic film applied directly to the surface protects up to 400°C (752°F).				●									
P.1-3	UNIV. PENNSYLVANIA NASA CR-111004 Title: Investigation of the Optical Properties of Si Solar Cell Component Materials	Dec 1969	Optical absorption coefficient of intrinsic silicon determined at a number of discrete wavelengths in spectral range 400-1000 nm at room temperature; irradiation of silicon with 6-MeV protons to fluences of 10^{16} particles/cm^2 does not produce any noticeable change in its optical properties.					○								
P.1-4	NASA Grant NGL-39-010-001 Title: Research for the Improvement of Silicon Solar Cell Efficiency Interim Report	Jan 1971	Develop a tool for investigating relationship governing the current voltage characteristic of the Si-solar cell. Computer program, developed to calculate the five parameters which determine I-V characteristics, was successful.					○						●		

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					SUBSTRATES	CELL COVERS	CELL INTER-CONNECT	SOLAR CELLS	POWER CONDITIONING	STOWAGE METHOD	PROTECTIVE PADDING	DEPLOY./ RETRACTION	END SUPPORT	SUPPORT STRUCTURE	POWER TRANSFER	EXTENDIBLE STRUCTURE
P.1-5	Energy Conversion Articles Vol II Title: A New Look at Silicon Solar Cell Performance	June 1970	Analysis made of large discrepancy between the ideal conversion efficiency predicted by the semiempirical deviations and the efficiencies actually achieved by production and laboratory cells. Results and potential improvements are discussed.					○								
	PHILCO FORD															
P.2-6	CR 109951 Title: Flight Data Analysis of Power System Degradation at Near Synchronous Altitude 3rd Quarterly Report Final Due	July 1970	Program established quantitative degradation rates of 19 IDSCS spacecraft power subsystems. Open circuit voltage curves, the best- and worst-case end parts calculated. I_{SC} degradation to cell above due to radiation is presented. The ratio of electron-to-proton damage is about 5:2.													
P.2-7	Contract: JPL 952585 Title: Engineering Experimental Program on the Effects of Near Space Radiation on Si-doped Solar Cells	Nov 1971	Presents results of experimental evaluation of real-time degradation characteristics of Li-doped Si solar cells. 6 months exposure to illumination in an ion pump vacuum chamber. Strontium-90 isotope for simulation of electron environment.					○								
	PICATINNY ARSENAL															
P.3-1	Title: Termination Procedures for Flat Conductor Cable and FLC	Feb	Detailed coverage of current state-of-the-art on the termination of flat multiconductor wiring, which includes flat parallel conductor cables and flexible printed circuitry.													
	PILKINGTON PERKIN-ELMER															
P.4-1	Specification Title: Solar Cell Coverslips	Sept 1969	Pilkington Perkin-Elmer Solar cell coverslip made of a new glass, designated CMS, which contains a small percentage of cerium oxide which prevents darkening of the glass and absorbs UV radiation.			○										
	RCA															
R.1-21	Vol 4 – No. 7 Title: Photovoltaic Power	July 1967	Gallium arsenide, cadmium sulfide, iridium phosphide, cadmium telluride and gallium phosphide single crystal single P-N junction cells are compared as to: material properties, efficiencies, and radiation resistance.													
R.1-22	IEEE Transactions Vol AES-2 No. 4 Title: Temperature Illumination Intensity and Degradation Factor Effects on Solar Cell Output Characteristics	July 1966	Presents a procedure which permits the construction of a solar cell I-V curve to include all factors affecting its performance. Solar cells test control and measurements are described. New I-V curve shifting procedure is discussed.													

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R.1-23 thru R.1-25	Contract: JPL 952555 Title: Study to Determine and Improve Design for Li-doped Solar Cells	March 1971	Program to study and analyze the action of lithium in producing a recovery of radiation damage in bulk silicon and silicon solar cells. Radiation damage and annealing model is presented to explain experiments.													
R.1-26	Applied Physics Letters Vol 9 – No. 1 Title: Lithium-doped Radiation-Resistant Silicon Solar Cells	July 1966	Results of experiments to improve radiation resistance of solar cells are described. Cells were irradiated with 1 MeV electrons and their electron and photovoltaic properties compared to standard cells. Recovery process is time and temperature dependent.													
R.1-27 thru R.1-29	CR-65656, -7, -8 Title: Manned Mission Photovoltaic Power System Study Vol 1 Program Summary Vol 2 Technical Discussion Vol 3 Supporting Documentation	June 1970	Definition of major problems associated with large-area solar array power systems for manned orbiting missions AAP or SKYLAB oriented design studies and trade-offs.	○												
R.1-30	5th Aerospace Mechanism Symposium (p. 165) Title: A Lightweight Bimetallic Actuator for Spacecraft Thermal Control	June 1970	Design, development, and construction of two types of active thermal-control (ATC) systems are described. Designs are based on controlled angular deflection of spiral wound bimetallic actuators. These actuators and a lightweight louver result in a simple design and low cost.													
	RAE															
R.3-12	TR-69126 Title: On the Infrared Response of Si Solar Cells as a Function of Thickness	June 1970	Performance of thin solar cells is compared with that of conventional thick cells. Equations are derived, using simple one-dimensional model, for the contribution to the response of a solar cell from the base region.													
R.3-13	TR-69044 Title: A Study of American Radiation Resistant Lithium Solar Cells	March 1969	Evaluation of 25 American lithium-doped P on N silicon solar cells following irradiation by 1 MeV electronics for fluences up to 10^{16} e/an^2. End of life performance was worse than that of conventional 10 ohm cm N on P cells.													

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R.3-14	TR-70171 Title: Magnetic Effects in Large Lightweight Solar Cell Arrays	Sept 1970	Results show that in a symmetrical array, effective cancellation of moments due to current loops can be achieved without running network leads directly underneath the cells. Interconnections of a ferromagnetic material interacting with Earth's magnetic field can give rise to unacceptable disturbing torques.				○		○						○	
R.3-15	J. British Interplanetary Society V. 24 Title: The Design of a Weather Satellite for Radiation Environment. Part 3, Solar Cell Power Supply	May 1971	Vehicle orbits in the 900 to 1500 nautical mile range. "Over-design" of solar cell area. Compensates for loss of power during mission due to radiation-induced degradation.													
R.3-16	TR-71075 Title: Power Decay Characteristic for a Solar Electrically Propelled Spacecraft	April 1971	Orbital transfer characteristics in terms of power and transfer time are described for a solar-electrically propelled spacecraft for transfers from various parking orbits to synchronous height, taking account of radiation environment degrading solar cells. Plots of percentage power loss vs transfer time are presented.													
R.3-17	IEEE Transactions Vol ED-16 No. 8 Title: Environmental Assessment of Thin Silicon Solar Cells from Pilot Production	Aug 1971	Performance capabilities of 4 mil cells determined (conventional and wraparound). Both 1 x 2 cm and 2 x 2 cm group cells from 1 and 10 cm boron doped silicon. All cells subjected "shelf-life" high ambient humidity and degradation by electron and proton irradiation transfer to synch altitude. Protection by various forms of coating investigated.					○								
	SANDIA LABORATORIES															
S.1-2	SC-RR-67-656A Title: Rolamite: A New Mechanical Design Concept	Dec 1967	A mechanical suspension system which reduces friction in the realm of extremely low bearing pressures. The basic geometry consists of two rolling elements inside parallel guide surfaces locked in a full-rolling counter-rotating "cluster" by an enlivened flexible metallic band under tension. All variations and applications are described.												○	○
	SPAR AEROSPACE															
S.4-2	AIAA Journal Vol 8 No. 11 Title: Solar Induced Bending Vibrations of a Flexible Member	Nov 1970	Stability of airplane bending oscillations of long flexible members (STEMS) when subjected to solar heating is examined. Motion is stable if STEM is sun oriented. Marginal for silver-plated STEM when it is oriented away from Sun. More accurate test information required.													○

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S.4-3	J. Spacecraft Vol 8, No. 11 Title: Observations on the Thermally Induced Twist of Thin Walled Open-Section Booms	Nov 1970	Various sources, including solar heating, that induce twisting are identified and evaluated. Reexamination of the problem of thermally induced twist with zero isothermal twist and of present rapid methods of predicting their steady-state behavior.													○
S.4-4	Contract: CSC-88-293 Title: Final Project Report for Rotary Power Transfer Device Development Program	March 1973	Not published yet. Not available for abstracting.												●	
	STANFORD UNIVERSITY															
S.6-2	NASA-SP-229 Proceedings of the Annual Working Group on Extraterrestial Resources Title: High Power Long Life Electrical Power System for Lunar Base Missions	1970	One nuclear and one solar cell system are described for this type mission. The effects of lunar base mission constraints and requirements are reviewed.													
	SPACE GENERAL CORP															
S.9-1 -2 Vol I & II	Contract: NAS2-3179 Title: Study of Conceptual Deep Space Monitor Communication System using a Single Earth Satellite	Sept 1970	Parametric analyses considering frequency bandwidth radiated power, data rate, antenna size, weight, and volume, and orbit inclination and altitude. Evaluation of antenna fabrication and deployment attitude control, power sources, and shielding was necessary. Systems integration and tradeoffs for planetary missions are considered.													
	TRW															
T.3-21	Contract: JPL 952554 Title: Study and Determination of an Optimum Design for Space Utilized Li-doped Solar Cells Quarterly Report	Oct 1970	Centralab and Heliotek Li-doped cells irradiated with 1 MeV electrons. The cells recovery characteristics were studied. Tungsten I-V characteristics on capacitance versus voltage measurements were obtained.													
T.3-22	IEEE Transactions Vol AES-6 No. 6 Title: Silicon Solar Cell Performance at High Intensities	Nov 1970	Various silicon cells (TiAg solder covered contacts 10 cm base resistivity) and 1 GaAs cell were exposed to light source ~625 watt 3400°K color temperature sun gun voltage stabilized with a SOLA Transformer. Electrical performance parameters plotted as function of illumination intensity.													

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T.3-23	IEEE Proceedings Vol 59, No. 2 Title: Photovoltaic Solar Arrays for Communication Satellites	Feb 1971	Design aspects of extendible arrays on three-axis-stabilized spacecrafts are discussed, including radiation effects on solar cells, substrates, selection of array voltage, analysis of shadows, and overall performance.													
T.3-24 T.3-25 (See also T.3-21	Contract: JPL 952554 Title: Study of Determination of an Optimum Design for Space Utilized Lithium-Doped Solar Cells Quarterly Final Report	April thru July 1971	Centralab cells evaluated for radiation resistance. Relation between initial cell output and lithium concentration confirmed. New data indicate that radiation defects acts as nuclei which allow the lithium donor to precipitate and neutralize the defect.													
T.3-26	AIAA Space Systems Meeting Title: Candidate Electrical Power Systems for Space Stations	July 1971	Description of three candidate systems is provided: Nuclear reactor (SNAP 8) Isotope-Brayton Skylab Type Solar Array-Battery 25Kve – 10 year life 270 nm orbit Space Shuttle resupply as requirements.													
T.3-27	IEEE Transactions Vol AES-7 No. 2 Title: Silicon Solar Cells at Low Temperature	March 1971	Experiment to obtain electrical characteristics of N-P silicon solar cells over temp range of +28 to -175°C and for illumination intensities from 140 to 1.5 mW/cm². Several hundred cells from various manufacturers are tested. Cells show low shunt resistance which makes them have a poor performance at low intensities.					○								
T.3-29	5th Aerospace Mechanism Symposium Title: Effects of Energy Dissipation in the Bearing Assemblies of Dual-Spin Spacecraft	June 1970	A convenient approximate expression with which to gauge the effects of bearing assembly flexibility on the attitude stability of dual-spin spacecraft is presented. An example of a possible application of this expression in a design role is described.	○												
T.3-30	IEEE Proceedings Vol 59, No. 2 Title: Photovoltaic Solar Array for Communication Satellite	Feb 1971	Extendible arrays on three axis stabilized spacecraft with increased power requirements are considered. Designs of these arrays are discussed with respect to radiation effects on cells, substrates selection of array voltage, analysis of shadows, and overall performance.													

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T.3-31	Contract: NAS2-6060 Title: Study of a Common Solar-Electronic-Propulsion Upper Stage for High-Energy Unmanned Missions	July 1971	Selected configuration-center body and two rollout arrays developing 17.5 KW at 1 AU. Mission types studied: memory orbiter, close approach solar probe, asteroid comet rendezvous, mission characteristics, scientific objectives, payloads and trade-offs presented.													
T.3-32	Title: Limitations of Solar Array Dark Forward Testing	1969	Demonstrated theoretically and experimentally that a dark forward test is neither a practical test for determining solar cell, submodule series-parallel string on array performance, nor for detecting degradation of cells within a submodule or string. The dark forward test method has value only in very limited applications.					○								
T.3-33	Contract: NAS5-11581 Title: Operating Manual-Fast Response Solar Array Simulator	Oct 1971	Basic concept described in detail, including theory of operation. Maintenance, calibration, and troubleshooting are described. Options for future expansion and improvement are presented.													
T.3-34	Contract: NAS8-21189 Title: Study to Establish Criteria for a Solar Cell Array for use as Primary Power Source for a Lunar Based Water Electrolysis System (Phase B) *Final Report*	Dec 1970	Developed three prototype solar cell Engineering Test Modules (ETM) using various substrate material (fiberglass lattice, Kapton and graphite lattice). These modules were environment tested. Certain development problems related to the cell stack design were solved and are reported.		○											
T.3-35	Contract: F33615-70-C-1361 Title: Hardened Flexible Solar Array Power System Presentation	Dec 1971	Solar array and power regulation and control unit hardening against weapon X-radiation. Development of laboratory simulation techniques of weapon X-radiation to study surface damage effects and thermoelastic failure.													
T.3-36 -37	Contract: MDAC-WD-70-2-004 Title: SAS Z-Vertical Study Vol I Summary Vol II Solar Cell & Module Tests & Analyses	Nov 1971	Determination of severity of cell reverse bias and associated solder melting and cell shorting rate. Investigation and analyses of cell shorting mechanism. Experimental verification of analytical method for calculating hot spot voltages and dissipations. Evaluation of structural integrity of solar cell stack under extreme temperature conditions, all for Skylab Orbital Workshop Solar Array (SAS).			●										

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